

Sustainable and resilient food systems in times of crises

Edited by

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and Hamid El Bilali

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Sustainable and resilient food systems in times of crises

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Editorial: Sustainable and resilient food systems in times of crises

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Editorial on the Research Topic

Sustainable and resilient food systems in times of crises

The global food system is facing multiple and multifaceted challenges and crises: increasing population, climate change, pandemics, conflicts, economic shocks, and natural disasters. These challenges have exposed its fragility and underscored the urgency of transitioning to sustainable and resilient food systems. Such systems ensure equitable access to nutritious food, minimize environmental impacts, and enhance resilience against shocks. In crises like the COVID-19 pandemic and the ongoing conflict in Ukraine, the vulnerabilities of the global food system have become starkly apparent, leading to disruptions in supply chains, food shortages, and inflation. Additionally, climate change and natural disasters further threaten food security worldwide. This Research Topic explores innovative approaches—including agroecological practices, circular economies, and localized food systems—to build resilience and sustainability. To provide a comprehensive understanding of these pressing issues, the 17 articles of this Research Topic are organized into four thematic areas: the impacts of crises on food systems, the effects of COVID-19 on food systems, sustainable food systems and practices, and the social, economic, and waste management dimensions of food systems.

The fragility of global food systems has been underscored by recent crises, including conflicts, natural disasters, and economic disruptions, which have exposed vulnerabilities in achieving food security and nutrition. For instance, the 2023 war on Gaza has significantly set back progress toward Sustainable Development Goal (SDG) 2 to end hunger. As highlighted by [Hassoun et al.](#), the ongoing war on Gaza has escalated acute food insecurity, with relentless bombardment and ground operations destroying agricultural lands, food production infrastructure, and Gaza's entire food system. Facing catastrophic hunger, some families eat animal feed and weeds to survive. This humanitarian disaster threatens global food security and progress on SDG 2. While international organizations strive to alleviate the situation, sustainable solutions addressing root causes are urgently needed to ensure adequate and nutritious food for Gaza's population.

Further, the Lebanese food system has been under stress due to many multiform crises and shocks, which makes it an interesting case study. [Makoukji et al.](#) shed light on the evolution of food (in)security status among residents in Karantina (a neighborhood in Beirut) after the explosion in Beirut Port in 2020. They showed a significant drop in food security and diet quality among residents during the 2 years following the explosion, with

nearly all the residents turning to crisis coping methods. They highlighted the need for assistance and reforms to restore food systems and enhance resilience in regions affected by crises.

Similarly, the disruption of grain trade caused by geopolitical tensions has threatened food security in the Middle East and North Africa (MENA) region, exacerbating existing vulnerabilities. [Rahimi et al.](#) demonstrated that 40% of dietary energy (1,261 kcal/capita/day) and 63% of protein (55 g/capita/day) in the MENA region come from imported grains, including 164 kcal and 11 g of protein from Russia and Ukraine. A complete halt in imports from these two countries would severely challenge food security in the region. This study emphasized the urgent need for proactive measures to ensure a stable food and feed supply.

Analyzing the resilience of food systems in six Asian countries amid the COVID-19 pandemic, geopolitical conflicts, and climate change, [Favas et al.](#) identify significant outcomes such as currency depreciation in Sri Lanka, Pakistan, and Lao PDR and widespread food price inflation. While countries with higher resilience capacities reported milder food insecurity impacts, others faced escalating vulnerabilities. Key trends include increased crop production and reduced food imports, with variations in government support. Recommendations emphasize integrating climate adaptation measures, enhancing resilience assessments, and adopting proactive intervention strategies to ensure long-term food system stability.

The COVID-19 pandemic is one of the most critical crises and shocks faced by the global food system, revealing vulnerabilities, and prompting adaptive responses across diverse contexts.

During the pandemic, Italy was the first European country to implement a nationwide lockdown, and schools were closed for a prolonged period. However, [Pagliarino](#) revealed that access to school meals was disrupted due to these closures, potentially decreasing student nutrient intake and household food security. Later, when schools were open, the service changed by responding to preventive measures defined at the central government level and implemented locally through coordination between municipalities, catering companies, and schools. Children, teachers, and families, i.e., the service's end users, were excluded from these discussions. The result was a mismatch between pandemic prevention goals and social values in school catering.

Similarly, the pandemic has disrupted the food system in Manitoba, Canada. However, [Lowitt et al.](#) confirmed that government measures, including funding for food banks and local food initiatives, helped mitigate disruptions. Nevertheless, food insecurity persisted, especially among vulnerable groups, with a 30% rise in food bank usage and challenges in Northern Indigenous communities. Labor shortages affected the agri-food sector, while interest in local food systems and urban gardening surged. The article emphasizes evaluating pandemic policies, monitoring food security for at-risk populations, and strengthening local food systems to enhance resilience and equity in post-pandemic recovery.

Likewise, the COVID-19 pandemic profoundly impacted food systems in China, highlighting significant challenges. For instance, [Han et al.](#) analyzed how the lockdown enacted in Shanghai in 2022 disturbed the city's food system and resulted in cases of food insecurity and the responses of the local government in

collaboration with various stakeholders. The solutions suggested aim, inter alia, at stabilizing food supply and prices, upgrading transportation capacity, and improving food access channels with a particular focus on vulnerable groups.

Moreover, [Fang et al.](#) investigate the impacts of the COVID-19 pandemic on the achievement of zero hunger in China, with a particular emphasis on improving nutrition. They postulated that the pandemic affected agricultural production and slowed down efforts to eliminate hunger and promote nutritional sustainability. Based on the findings covering 29 provinces in China, they formulated several policy recommendations, such as establishing a robust natural disaster prevention and control system and fostering agricultural technological innovation to mitigate the adverse effects of food security emergencies and strengthen the resilience of food systems in the future.

Further, with the challenges faced by institutional food services during the pandemic, the focus shifts to alternative food networks (AFNs) that emerged as vital mechanisms for resilience and adaptation. In the Czech Republic, the results of [Smutná et al.](#) showed that 68% of Czech households engage in AFNs, including gardening and market-based options like farmers' markets and farm gate sales. However, COVID-19 and economic pressures in 2021 led to reduced consumption of organic food (−22%) and fresh produce (−10%) and increased food insecurity (+18%). The article explores the role of AFNs in supporting food and nutritional resilience while addressing challenges that threaten market-oriented AFNs.

Building sustainable food systems is essential for addressing environmental challenges, enhancing resilience, and ensuring equitable access to nutritious food.

In Tunisia, the study of [Souissi et al.](#) underlined that farmer organizations play an essential role in advancing sustainable farming through clear goals and collaboration despite challenges like input scarcity, water shortages, low income, and market access. Over 90% of farmers receiving agroecological training reported adopting new practices, with the olive oil value chain showing strong potential for transformation despite constraints like climate and lack of policy support. Key drivers include agroecological practices' compatibility with farmer skills and their environmental and economic benefits. The study emphasizes participatory approaches and socio-technical systems analysis to address barriers, integrate diverse farmer perspectives, and support Tunisia's transition to sustainable, resilient food systems.

In Burkina Faso, [Tapsoba et al.](#) underscored the crucial role of the food environment in achieving sustainable food systems. This is due, among others, to the centrality of the food environment in reducing malnutrition in all its forms and combating non-communicable diseases. Against this backdrop, they use the Healthy Food and Environment Policy Index (Food-EPI) methodology with a group of national experts to develop and prioritize actionable recommendations for the Burkinabe government to establish a healthy food environment. They formulated 20 recommendations related to policy (e.g., regulating food advertising/marketing) and infrastructure support (e.g., investments in population nutrition) domains.

Further, [Singh et al.](#) explore the indigenous chicken production system (ICPS) in three agro-ecologies of the Indian Himalayan

Region, examining its role in food and economic security. Findings reveal that sub-temperate regions have larger flock sizes, higher egg production, and better household dietary diversity than tropical and sub-tropical zones. ICPS contributes 18% of household income in sub-temperate areas despite challenges like disease, predation, and limited chicken availability. The system enhances ecological resilience through farmyard manure use but requires targeted health and management interventions to boost productivity.

Finally, [Maulu et al.](#) examine the role of fish in addressing food and nutrition security challenges across 10 Southern African countries, including Angola, Zambia, and South Africa. Persistent issues such as overfishing, climate shocks, and limited aquaculture investment hinder fish production, while inadequate access to quality inputs further exacerbates malnutrition. Opportunities exist to promote sustainable fisheries and aquaculture, especially in landlocked nations exploring aquaculture solutions. Countries with extensive coastlines show potential for fishery development. Addressing these challenges requires governance reforms, technological innovation, policy support, and investment to enhance sustainability and resilience in the region's fisheries and aquaculture industries.

Understanding the social, economic, and waste management dimensions of food systems is vital for fostering equity, reducing waste, and enhancing resilience in the face of crises.

In Italy, [Catalano et al.](#) examined food waste awareness among university students, highlighting key attitudes, behaviors, and opportunities for promoting sustainable consumption practices. The survey reveals high engagement in sustainable food purchasing but low adherence to waste prevention practices at home. Key factors influencing food waste include lack of involvement in grocery shopping and male gender. Among subgroups, only those with structured nutrition education handled “use by” products significantly better than peers without such training. These findings highlight the importance of targeted education to improve food management behaviors and reduce waste.

In Ethiopia, [Wubetie et al.](#) analyzed food insecurity using a geo-additive model and household survey data from 2012–2016. The study identifies northern and south-western Ethiopia as food insecurity hotspots, while the southeast and northwest are more food secure. Factors such as education, employment, urbanization, and agricultural practices reduce food insecurity, while natural disasters, small land ownership, and unemployment worsen it. The study highlights the role of rural vs. urban living, early marriage, and household size. The authors recommend targeted interventions in high-risk areas and further research on spatial effects and non-linear covariates in conflict-affected regions.

In Chile, [Kanter et al.](#) conducted a pilot study to assess a digital literacy intervention to strengthen local food systems. Targeting smallholder farmers, vendors, and consumers, the study sought to improve information and communication technologies (ICT) use amidst crises like the 2019 social unrest, COVID-19, and climate change. A 5-week intervention successfully boosted digital literacy, particularly among farmers and vendors. The study found a shift in food purchasing behavior, with more reliance on delivery services

and social media-driven access during the pandemic. The research highlights the importance of digital literacy in enhancing food system resilience and recommends expanding such programs to other regions.

In Canada, [Taylor et al.](#) examine the ethical challenges facing Canadian grocers amid rising food prices and accusations of profiteering. Using consumer, watchdog, and industry data, the study highlights shifting public perceptions toward grocery chains. The authors argue that transparency and mandatory codes of conduct could restore trust while paradoxically resulting in the continued growth of corporate profit when societal needs are no longer perceived as being neglected or exploited. The analysis underscores the need for improved corporate accountability and transparent financial reporting to balance profit-making with public good.

Overall, the articles included in the Research Topic provide valuable insights into the sustainability and resilience of food systems in times of crises and shocks. They not only shed light on how crises and shocks, with a particular focus on the COVID-19 pandemic, impact food systems in terms of activities, functions, and outcomes but also highlight different practices as well as management and governance arrangements contribute to the transition toward sustainable and resilient food systems. Further research is needed to elucidate the sustainability-resilience nexus in food systems better and identify pathways to operationalize their functional linkages to prevent and/or mitigate the impacts of future crises and shocks.

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Indigenous chicken production system in different agro-ecology of Indian Himalayan Region: implication on food and economic security

Mahak Singh^{1*}, R. N. Patton², R. T. Mollier², N. Pongener², Rekha Yadav³, Vinay Singh⁴, Rahul Katiyar⁴, G. D. Singh⁵, Sourabh Deori⁴, Sunil Doley⁴, J. K. Chaudhary⁶, Subhash Babu⁷, H. Kalita² and V. K. Mishra⁴

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The indigenous chicken production system (ICPS) has several use values and ecosystem services. In the last few years, ICPS has been recognized for its possible contribution to household food security, income generation, wildlife protection, and bettering the women's lives. This study aimed to collect, for the first time, comprehensive information about ICPS in three different agro-ecologies (tropical, sub-tropical, and sub-temperate) of the Indian Himalayan Region (IHR) and its role in food and economic security of traditional communities. In this study region, ICPS is semi-extensive, providing homegrown feed and temporary night shelter. In sub-temperate agro-ecology, females owned non-significant ($p = 0.170$) more indigenous chicken flocks than males. Households in sub-temperate agro-ecologies had significantly ($p \leq 0.001$) larger flock sizes and tropical livestock units (chicken-TLU). However, the livestock diversity index (LDI) was significantly higher ($p \leq 0.001$) in tropical and subtropical agro-ecology. The households in the sub-temperate region highly ($p \leq 0.001$) valued indigenous chicken because of its survivability and adaptability. In absolute numbers significant ($p \leq 0.001$) higher numbers of adult birds died in past 1 year in sub-temperate agro-ecology. The mortality rate of adult birds in sub-temperate agro-ecology was 9%, and it was 14 and 15% in tropical and sub-tropical agro-ecologies, respectively. In sub-temperate agro-ecology, larger flock size translated into significantly higher ($p \leq 0.001$) egg production and subsequently a significant ($p \leq 0.001$) higher egg consumption per household per month. In sub-temperate agro-ecology, households' dietary diversity score was significantly ($p \leq 0.001$) higher. Similarly, the average annual income from ICPS was significantly higher ($p \leq 0.001$) in sub-temperate agro-ecology and accounted for 18% of household income. ICPS' marketing chain was relatively short in the sub-temperate region. In all agro-ecologies, indigenous chicken and egg demand was significantly higher ($p \leq 0.001$) in the winter. ICPS litter is used as farmyard manure, enhancing ecological resilience. In all agro-ecologies, the three most frequently cited obstacles to extending the indigenous chicken production system are illnesses, predators, and a lack of chicks availability. ICPS contributes to food and nutritional security, economic stability, and ecological resilience in this hilly and fragile ecosystem. Even though

the system is self-sustaining, management and health interventions can increase production and productivity.

KEYWORDS

indigenous chicken production system, Indian Himalayan Region, food security, economic security, ecological resilience

1. Introduction

Indigenous food systems are highly productive, sustainable, and equitable. These systems preserve rich biodiversity, provide nutritious food, and are climate resilient (1). Indigenous people's food systems are rooted in traditional knowledge and customary systems, which ensure their existence and well-being despite several challenges (2). Indigenous food systems are essential for food security and food sovereignty since they are founded on millennia of collected knowledge. These food systems are vital for cultural identity, spiritual well-being, and land stewardship. Indigenous Peoples are reviving their agro-ecological food systems because they are more resilient to climate change and provide more nutritious diets than modern food systems.¹ One such food system is the indigenous chicken production system (ICPS) which has several use values and ecosystem services (3–5).

The indigenous chicken production system (ICPS) is a climate resilient and sustainable food system in low- and middle-income countries (LMICs), especially in fragile ecosystems (5–7). Indigenous chickens account for 80% of the chicken population in Africa (8), and in India, 35% of poultry products come from the indigenous chicken production system (7). Although their productivity is lower than that of intensively raised birds (9), indigenous chickens contribute to food and nutritional security, economic security, and ecological resilience (3, 5, 10). In Indian Himalayan Region (IHR), the indigenous chickens have been part of the indigenous food system of tribal and indigenous people for centuries (7, 11).

The Indian Himalaya Region stretches 2,500 km across 12 states and covers 53.7 Mha. This is ~17% of the country's total geographical area. It is home to 52 million indigenous and tribal people. The IHR is a source of food, water, and energy for 1.5 billion people. There are five agroecological zones in IHR, ranging from cold arid to warm and humid. The mean annual precipitation ranged between 150 and 4,000 mm. The average annual temperature fluctuates between 8°C and 22°C (12). Environmental, biological, socio-cultural, and economic variations in the Himalayas have led to the evolution of diverse and unique indigenous food production systems involving crop species, and livestock (13). Indigenous people's food has animal source food (ASF) to meet their dietary requirements. The indigenous chicken production system is an important enterprise for tribal farmers in the IHR (7, 11). However, of late indigenous food systems in the IHR are threatened by deforestation, climate changes, migration, the introduction of an intensive agricultural production system (14), changes in dietary habits, mono-cropping, commodity crops, soil degradation, and market decline.

Despite its enormous contribution to the nutritional and economic security of the Indian Himalayan Region, the indigenous chicken production system is poorly studied as a food system. There is no information available on the characteristics of the indigenous chicken production system in different agroecologies in the Indian Himalayan Region. Knowledge about the characteristics and management practices (including health and bio-security) of indigenous chicken and its role in food and nutritional security are therefore of value to academicians and policy planners to further improve upon the existing food system. Hence, the present study aims (i) to characterize the indigenous chicken production system in three different agro-ecologies (tropical, sub-tropical, and sub-temperate) of the Indian Himalayan Region along with health and biosecurity status, (ii) to identify the indigenous chicken market chain, (iii) to investigate the role of ICPS in food and economic security of households and (iv) to identify the challenges for increasing the system's productivity on a sustainable basis.

2. Materials and methods

2.1. Study site

The study was conducted in three agroecologies (tropical, sub-tropical, and sub-temperate) of the Indian Himalayan Region. The study site is located in Nagaland, a Himalayan state in North East India (Figure 1). Table 1 describes three agroecologies, districts, and sample size. Nagaland is a mountainous state of India and lies at 93° 20'E and 95° 15'E Longitude, and 25° 6' and 27° 4' N Latitude with an altitude ranging from 111 to 3,840 m above mean sea level. Nagaland shares an international boundary with Myanmar to its east. Nagaland is inhabited by an indigenous tribal population and has 16 major tribes and numerous minor tribes. In the region, almost 71% of the population depend on agriculture for their livelihood. *Jhum* or slash and burn cultivation is practiced in the study area. Nagaland's agriculture production system has been close to proto-agriculture, which has enabled close links between nature and people through generations. These traditional practices have been formalized through experiences, and empirical observations, and are deeply rooted in socio-cultural and traditional values.

2.2. Sample size and questionnaire development

For sample size calculation, methodology of Thrusfield et al. (15) was used ($n = Z^2 P(1 - P)/d^2$; where n is the sample size, Z is the statistic corresponding to level of confidence, P is expected

¹ <https://www.iied.org/indigenous-peoples-food-systems-hold-key-feeding-humanity>

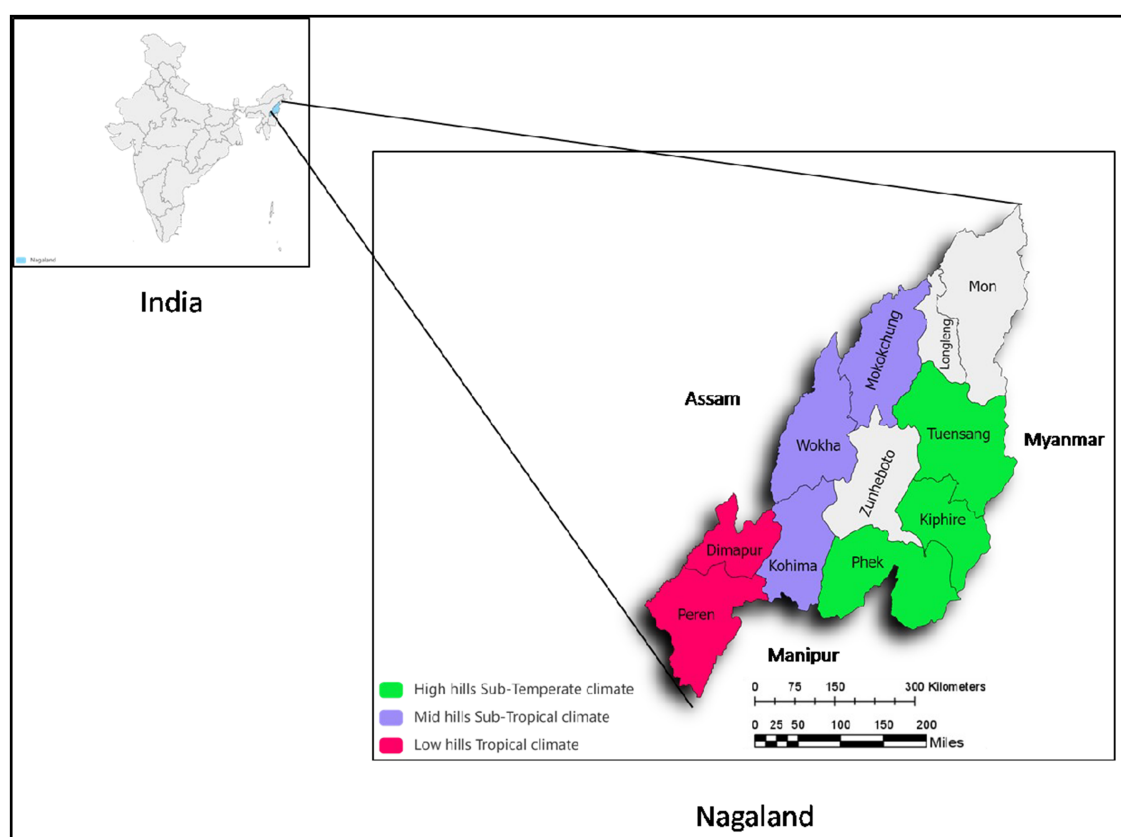


FIGURE 1
Study location depicting different agro-ecologies in Indian Himalayan Region.

prevalence, and *d* is precision). In each agroecology, the sample size was calculated at 139 based on 70% prevalence (approximately 70% of the population relies on agriculture and related sectors), 99% confidence intervals, and 10% absolute precision. In total, 595 households participated in the study in all three agro-ecologies (Table 1). In sub-tropical and sub-temperate climates, fewer households were studied due to a smaller population, inaccessible terrain, and limited funds. The authors developed a semi-structured questionnaire based on interviews with village chicken owners, field observations, and the relevant literature (10, 16–18). The pilot survey was conducted in two villages using 10 households (five from each village). Following the pilot, the questionnaire was modified to improve clarity. The final questionnaire has eight sections on the socioeconomic status of households, indigenous chicken flock and other livestock on the farm, reason for rearing indigenous chicken, management of indigenous chicken, food and economic security of households, marketing chains of indigenous chicken, health and biosecurity status of the indigenous chicken unit and constraints to expand the indigenous chicken unit.

2.3. Study details

Households were selected through a multistage random sampling procedure at the district, block, and village levels. In brief, in each agroecology, eight rural blocks were selected and in each block, two

villages were randomly chosen. In the villages, households rearing indigenous chickens were chosen by proportional allocation using a 5% sampling fraction. A pre-tested semi-structured questionnaire was used by the research team to gather the necessary data from the households through face-to-face interviews. Each interview lasted about 40 to 50 min. Data were collected in pen and paper mode, verified by the first author and entered into a Microsoft Excel sheet on the same day. Households verbal consent was requested and granted before data collection began.

The socioeconomic status of households, indigenous chicken management system, marketing chain, and health and biosecurity status of indigenous chicken units were mapped. Data on annual income and income from indigenous chickens were determined after consensus between households and village council members. There may be some biases in income data which cannot be avoided at the field level, however, consensus is the best way to reduce biases (16). A comprehensive inventory of indigenous chicken and other livestock species raised by households was taken at the visit. Chicken Tropical Livestock Unit (TLU) was calculated as per (19). The livestock diversity index was calculated using the Margalef index (20) as it discriminates well and fits well compared to other diversity indices. In addition, it captures a variety of animal species. Household perceptions regarding indigenous chicken rearing were recorded after reaching consensus among adult household members. Most households choose multiple preference indicators.

TABLE 1 Description of different agro-ecologies under study in Indian Himalayan Region (https://statistics.nagaland.gov.in/storage/statistical_data/2021/2811617325911.pdf).

Agro-ecology	Study districts	Households numbers	Description
Low hills tropical climate	Dimapur and Peren	235	Altitude: <500 m above mean sea level,
			Annual rainfall: 1,400 to 1,500 mm mostly during southwest monsoon from May to September.
			Mean monthly temperature: 15°C to 30°C
			Major crops: Rice, Toria, Maize, Soybean, linseed
Mid hill sub-tropical climate	Mokokchung, Kohima and Wokha	192	Altitude: 500 to 1,500 m above mean sea level,
			Annual rainfall: 1,400 to 2,000 mm mostly during southwest monsoon from May to September.
			Mean monthly temperature: 11.60°C to 29.10°C
			Major crops: Upland rice, Maize, Coffee, Tea, Tapoica, Cassava, sweet potato
High hills sub-temperate climate	Tuensang, Phek and Kiphire	168	Altitude: 1,500 to 2,500 m above mean sea level,
			Annual rainfall: 1,400 to 1,700 mm mostly during southwest monsoon from May to September.
			Mean monthly temperature: 10°C to 19.10°C
			Major crops: Maize, Frenchbean, Upland rice, Soybean, Foxtail millet, Tapoica, Cassava

Data on food and economic security contributed by indigenous chickens were collected on a household recall basis (21). Most of the time, the recall was done by consensus of family members with the adult members of the households being the principal respondents. Egg consumption per month for households and children (less than 6 years of age) was also recorded by the recall. It is well-established that consensus recalls are more accurate and representative than individual responses (16). We also assessed the Household Dietary Diversity score (HDDS) as a measure of food security in the region as per FAO (22) recommendation. The HDDS is meant to reflect, in a snapshot form, the economic ability of a household to access a variety of foods (20). A more HDDS is correlated with caloric and protein adequacy, percentage of proteins from animal sources, and household income. As the indigenous chicken production system is a vital part of the indigenous food system in the region. Therefore, we hypothesized that expanding indigenous chicken flock sizes would increase food and economic security. Households can, however, determine whether their flock is sustainable by learning through experience and observing their constraints. To expand indigenous chicken flocks, we asked households to rank the constraints from most significant (1) to least significant (8).

2.4. Statistical analysis

The data were checked and completeness was evaluated. Shapiro–Wilk test was performed to check the normal distribution of continuous data. Descriptive statistics were generated for all the variables in the dataset using SPSS software (Statistical Package for Social Science version 27.0). The results were summarized by questions based on frequency and percentage for categorical variables. The Pearson Chi-square test was used to compare qualitative variables between different agro-ecology. Descriptive statistics analyzed quantitative variables using one-way ANOVA followed by a Tukey's *post-hoc* test. The difference in mean values for all data analyzed with $p < 0.05$ was considered significant.

3. Results

3.1. Summary statistics of households' socio-economic status

Sub-temperate agro-ecologies had a higher proportion ($p \geq 0.05$) of female respondents (62%) than tropical and sub-tropical agro-ecologies (Table 2). There was no significant difference in respondents' age between the three agro-ecologies. The size of families and children were significantly higher ($p \leq 0.001$) in sub-temperate agro-ecologies. Education levels ($p \leq 0.001$) and land holdings ($p \leq 0.01$) were significantly higher in tropical and sub-tropical agro-ecologies. The total annual income of households was similar across the three agro-ecologies ($p \geq 0.05$).

3.2. Households' chicken flock size and livestock diversification index

Analysis of the flock inventory (Table 3) showed that total chickens, as well as individual age group chickens were significantly higher ($p \leq 0.001$) in sub-temperate agro-ecology. Similarly, the number of chicken tropical livestock units was significantly higher ($p \leq 0.001$) in sub-temperate agro-ecology. However, livestock types ($p \leq 0.001$) and livestock diversity index ($p \leq 0.001$) were significantly higher in tropical and subtropical agro-ecology than sub-temperate agro-ecology (Figure 2).

3.3. Households' perception for rearing indigenous chicken

In all agro-ecologies (Table 4), indigenous chickens were valued for their adaptability and survivability, however in sub-temperate agro-ecology (83%), this was significantly higher ($p \leq 0.001$). Rearing indigenous chicken for meat and egg taste was stated criteria by 31%, 36%, and 41% in tropical, sub-tropical, and sub-temperate agro-ecology, respectively. Scavenging ability and egg production traits

TABLE 2 Socio-economic description of the households rearing indigenous chicken in different agro-ecologies of Indian Himalayan Region.

Characteristics	Description	Tropical climate (No. = 235)	Sub-tropical climate (No. = 192)	Sub-temperate climate (No. = 192)
Gender of the respondent %	Male	46.8	46.4	38.1
	Female	53.2 ^b	53.6 ^b	61.9 ^a
Age of the respondent	Mean ± SE	46.04 ± 2.57 ^a	45.21 ± 3.78 ^a	46.91 ± 2.89 ^a
Total family size	Mean ± SE	6.04 ± 0.064 ^b	5.45 ± 0.060 ^c	6.91 ± 0.087 ^a
Children	Mean ± SE	3.0 ± 0.05 ^b	2.48 ± 0.04 ^c	4.07 ± 0.06 ^a
Education %	Educated	87.2 ^a	76.6 ^b	67.9 ^c
	Illiterate	12.8 ^c	23.4 ^b	32.1 ^a
Primary occupation %	Agriculture	80	85.4	79.8
	Others	20	14.6	20.2
Land holding (ha)	Mean ± SE	0.75 ± 0.027 ^a	0.81 ± 0.044 ^a	0.62 ± 0.048 ^b
Total annual income (Indian rupees in thousand)	Mean ± SE	42.2 ± 0.07 ^a	41.8 ± 0.11 ^a	40.7 ± 0.14 ^a

Different superscript in a row denotes significant difference at $p < 0.05$.

TABLE 3 Inventory of indigenous chicken reared in different agro-ecologies of Indian Himalayan Region.

	Tropical climate	Sub-tropical climate	Sub-temperate climate
Hen	3.39 ± 0.07 ^c	5.41 ± 0.09 ^b	8.43 ± 0.19 ^a
Cocks	1.84 ± 0.04 ^b	1.55 ± 0.04 ^c	2.63 ± 0.07 ^a
Pullets	2.67 ± 0.06 ^b	2.21 ± 0.03 ^c	4.35 ± 0.05 ^a
Cockerels	2.57 ± 0.05 ^b	2.41 ± 0.04 ^c	4.49 ± 0.05 ^a
Chicks	7.89 ± 0.06 ^b	6.98 ± 0.08 ^c	11.50 ± 0.18 ^a
Total Chicken	18.35 ± 0.14 ^b	18.56 ± 0.11 ^b	31.40 ± 0.30 ^a
Number of livestock type	2.51 ± 0.04 ^a	2.41 ± 0.04 ^a	2.09 ± 0.04 ^b
Chicken TLU	0.23 ± 0.00 ^b	0.24 ± 0.00 ^b	0.40 ± 0.00 ^a

Different superscript in a row denotes significant difference at $p < 0.05$.

were preferred by 44.76% and 42.97% of households in sub-temperate agro-ecology.

3.4. Production system of indigenous chicken production system

The majority of households rear indigenous chickens for meat and eggs (Table 5). Most households built their chicken coops using locally sourced materials (bamboo, wood, and grass). The chicken house cleaning was undertaken mostly by females whereas feeding and watering were looked after by both male and female. A significantly ($p \leq 0.001$) higher proportion of households offered homegrown feed in all the agro-ecologies, however, this was much higher in sub-temperate agro-ecology (93%).

3.5. Food and economic security contributed by indigenous chicken

In sub-temperate agro-ecology, the numbers of eggs produced were significantly higher ($p \leq 0.001$) than in tropical and

sub-tropical agro-ecologies (Table 6). Similarly, households in sub-temperate agro-ecology sold and consumed significantly higher ($p \leq 0.001$) numbers of indigenous chicken eggs (Figure 3) and adult birds. Significantly higher ($p \leq 0.001$) numbers of eggs were left for hatching in sub-temperate agro-ecology. In absolute numbers significant ($p \leq 0.01$) higher numbers of adult birds died in the last year in sub-temperate and sub-tropical agro-ecologies. However, mortality in adult birds constitutes approximately 9, 14, and 15% of the total flocks in sub-temperate, tropical and sub-tropical agro-ecologies, respectively. Survivability of chicks for up to 6 weeks was significantly higher ($p \leq 0.001$) in tropical and sub-tropical agro-ecologies. Economically, annual income from indigenous chicken was significantly higher ($p \leq 0.001$) in sub-temperate agro-ecology. Income from indigenous chickens contributed 18, 12 and 10.52% to total households' income in sub-temperate, tropical and sub-tropical agro-ecology, respectively. The households' dietary diversity score was significantly higher ($p \leq 0.001$) in sub-temperate agro-ecology (Figure 4).

3.6. Marketing practices of indigenous chicken

The majority of households raised chickens for self-consumption and commercial purposes across the different agro-ecologies (Table 7). Prices of adult birds and eggs were higher in the sub-temperate region. Although the majority of households reported getting a fair price for birds and eggs, the price was significantly higher ($p \leq 0.05$) in sub-temperate agro-ecology. In the sub-temperate region, most households sold chicken and eggs at local markets, whereas, in tropical and subtropical areas, the home and the local markets were almost equally significant points of sale. In the tropical and subtropical regions, middlemen purchased more chickens and eggs ($p \leq 0.001$), whereas the majority of households in the sub-temperate region sold chicken and eggs to the consumer. The demand for indigenous chicken and eggs was significantly higher ($p \leq 0.001$) in the winter season in all agro-ecologies.

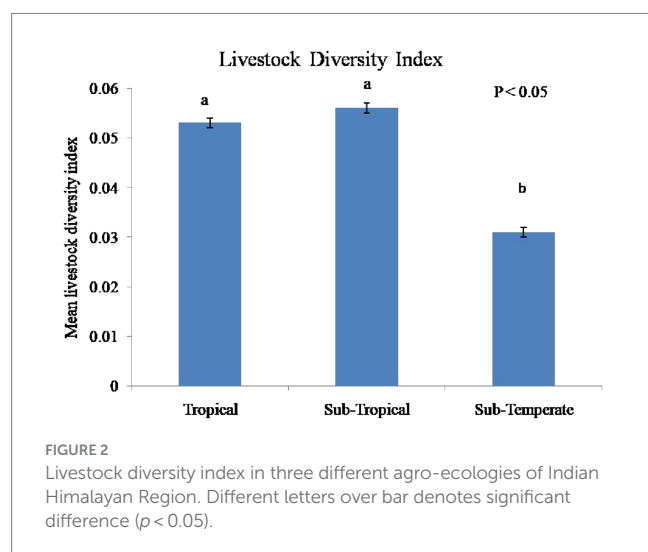


TABLE 4 Farmers' perception (%) for rearing indigenous chicken in three different agro-ecologies of Indian Himalayan Region.

Perceptions	Tropical climate	Sub-tropical climate	Sub-temperate climate
Adaptability and survivability	61.70	65.10	83.33
Meat and egg taste	31.48	36.45	41.66
Less feed and other inputs	19.14	17.70	17.85
Scavenging	29.36	37.29	44.76
Eggs number	22.12	25.20	42.97
Growth rate	12.12	26.25	32.38

3.7. Health and bio-security measures of village chicken

Table 8 presents the health and bio-security status of indigenous chicken production systems in different agro-ecologies. The majority of households in tropical and sub-tropical agro-ecologies reported the highest ($p \leq 0.001$) mortality during the rainy (Monsoon) season. During winter, mortality was significantly ($p \leq 0.001$) higher in sub-temperate agro-ecology than the other two agro-ecologies. The majority of households did not know about NCD and did not do any vaccination. The majority of households used poultry litter as farmyard manure in all agro-ecologies. Bio-security practices were not followed by most households in all agro-ecologies. The majority of respondents did not follow regular cleaning and disinfection, all-out and all-in systems, isolation of sick birds, and hand washing before and after handling poultry. The majority of respondents reported rodent and wildlife access to feed stores or chicken coops.

3.8. Constraints of indigenous chicken production system

Predators, non-availability of chicks, and diseases were the three most reported constraints to expanding the indigenous chicken production system in all agro-ecologies (Table 9). Chicken housing,

poor marketing infrastructure, and feed scarcity were the three least ranked constraints by households in the Indian Himalayan Region.

4. Discussion

The present study characterizes the indigenous chicken production system, along with its contribution to the food and economic security of the tribal communities in the Indian Himalayan region. The percentage of indigenous chicken units owned by women was higher in sub-temperate agro-ecology. It has previously been reported that in less developed regions, indigenous chicken is generally owned and managed by women (7, 17, 23, 24). In sub-temperate agro-ecology, the respondents had less education level. In contrast with the other two agro-ecologies, the sub-temperate agro-ecology is remote, rugged, sparsely populated, and less developed. The primary occupation of the majority of households is agriculture, and their landholding is less than 1 ha. In developing regions, native chicken rearing integrated with agriculture is a century-old traditional livelihood for the rural poor who earn their living on less than 2 ha of land (5, 6, 25, 26).

The total flock size was larger in sub-temperate agro-ecology. Similarly, Chicken-TLU was higher in sub-temperate agro-ecology. However, livestock types and livestock diversity was less in sub-temperate agro-ecology. In contrast to our findings, Haile and Biratu (27) reported that in Ethiopia, farmers in lowland areas keep a higher number of chickens per household than in midland and highland areas. The greater size of indigenous chicken flocks and the lower LDI in sub-temperate agro-ecology indicate a greater reliance on chicken for food and economic security. There is also the possibility that sub-temperate regions might have a higher scavenging feed resource, which could be the reason for the higher chicken population. In all ecologies, chicks make up about 35 to 40% of the flock. The cock to hen ratio ranged from 1.84 to 3.5 in different agro-ecologies. Nonetheless, the flock size per household was less than 50 in all three agro-ecologies. As per the FAO (28) classification, this is an extensive scavenging indigenous poultry production system. In sub-temperate regions, flock sizes tend to be larger, indicating higher genetic polymorphism and, therefore, a wider variety of phenotypic traits and they can serve as the reservoirs of indigenous chicken genetic resources (3). There is high genetic polymorphism in indigenous chickens and this increases with flock size (3, 4), particularly the number of cocks. Households in tropical and sub-tropical agro-ecologies have fewer indigenous birds because they rely on other livestock, as reflected by a higher livestock diversity index. Also, these agro-ecological regions are better connected to major towns in the region and therefore may have easy access to animal-source food. It was earlier reported that the flock size of indigenous chickens varies considerably within and across the regions. This is because of different factors like the purpose of rearing, the socio-economic status of households, etc. (23, 29).

In all three study regions, households prefer to rear indigenous chickens mainly because of their adaptability and survivability, meat and egg taste, and scavenging ability. Indigenous chickens have developed through natural selection in adverse climatic conditions and therefore have accumulated high genetic diversity, making them hardy, resilient to disease, and high survivability (4, 5, 9, 17, 30). The climatic conditions are harsh in sub-temperate agro-ecology and

TABLE 5 Management of indigenous chicken in different agro-ecologies of Indian Himalayan Region.

Characteristics		Tropical climate (No. = 235)	Sub-tropical climate (No. = 192)	Sub-temperate climate (168)
Purpose of chicken rearing %	Egg	16.2	14.6	10.1
	Meat and Egg	83.8	85.4	89.9
Type of poultry house %	Temporary	91.9	92.7	92.9
	Permanent	8.1	7.3	7.1
Location of the house %	Backyard	92.3	95.3	92.9
	Front	4.7	2.1	4.8
	Side	3	2.6	2.4
Source of housing material %	Local	92.3	87.5	91.7
	Market	7.7	12.5	8.3
Who looks after cleaning %	Male	13.6	16.7	17.9
	Female	86.4	83.3	82.1
Who looks after feeding and watering %	Male	1.7	1.6	0.6
	Female	9.4	7.3	21.4
	Both	88.9	91.1	78
Type of feed offered %	On-farm	57 ^c	68.8 ^b	92.9 ^a
	Market	11.9 ^a	14.6 ^a	2.4 ^b
	Both	31.1 ^a	16.7 ^b	4.8 ^c

Different superscript in a row denotes significant difference at $p < 0.05$.

TABLE 6 Food and economic security contributed by indigenous chicken in Indian Himalayan Region.

Characteristics	Tropical climate (No. = 235)	Sub-tropical climate (No. = 192)	Sub-temperate climate (No. = 168)
Egg produced in past 1 month	7.88 ± 0.13 ^c	15.64 ± 0.36 ^b	28.48 ± 0.38 ^a
Egg sold in past 1 month	0.17 ± 0.05 ^c	1.38 ± 0.18 ^b	5.73 ± 0.23 ^a
Eggs left for hatching	6.97 ± 0.13 ^b	6.72 ± 0.17 ^b	13.15 ± 0.20 ^a
Hatching percent	85.46 ± 0.37 ^a	82.66 ± 0.36 ^b	85.45 ± 0.44 ^a
Survivability percent (up to 6 weeks)	89.60 ± 0.23 ^a	88.44 ± 0.34 ^{ab}	87.51 ± 0.34 ^b
Adult birds sold in past 1 year (no.)	9.88 ± 0.49 ^b	8.73 ± 0.15 ^c	12.24 ± 0.15 ^a
Adult birds consumed in past 1 month (no)	3.14 ± 0.05 ^b	2.45 ± 0.04 ^c	4.55 ± 0.05 ^a
Adult bird died in last 1 month	0.33 ± 0.03 ^b	0.39 ± 0.04 ^{ab}	0.47 ± 0.04 ^a
Birds died in past 1 year	2.59 ± 0.06 ^b	2.83 ± 0.07 ^a	2.94 ± 0.08 ^a
Annual income from Chicken	5.14 ± 0.02 ^b	4.4 ± 0.03 ^c	7.34 ± 0.04 ^a
Contribution of Chicken income to total income (%)	12.18 ^b	10.52 ^b	18.03 ^a

Different superscript in a row denotes significant difference at $p < 0.05$.

therefore, adaptability and survivability were the main preference criteria for indigenous birds. Native chicken is also preferred because it requires less feed and inputs, produces more eggs, and grows faster. Previous studies have documented that indigenous people prefer native birds because their meat and eggs are tastier, and needed for traditional ceremonial meals (23, 24, 31, 32).

The majority of households rear indigenous chickens for eggs and meat. The management includes a temporary chicken coop for night shelter built with locally available materials. Indigenous birds have multifaceted uses unlike commercial broilers and layers, and they are preferred for egg and meat production (3). Similarly, Kumaresan et al. (11) and Singh et al. (14) reported that indigenous people preferred

local birds because of their lean and hard meat. Meat and eggs from indigenous chickens constitute a high-quality food source, densely packed with essential macro- and micronutrients, and play a significant role in the nutritional security of the rural poor (5). Native chickens produce stronger flavored meat with a firmer texture than broiler meat, which makes them highly preferred by traditional communities (29). Households in all agro-ecologies used on-farm production as their primary source of chicken feed, while sub-temperate regions had the highest levels. This is in agreement with earlier reports (5, 11, 33). Traditionally, indigenous chickens live mainly on scavenging and receive minimal supplementary feeding from kitchen waste or household farm produce (5, 11, 23). Besides, scavenging helps

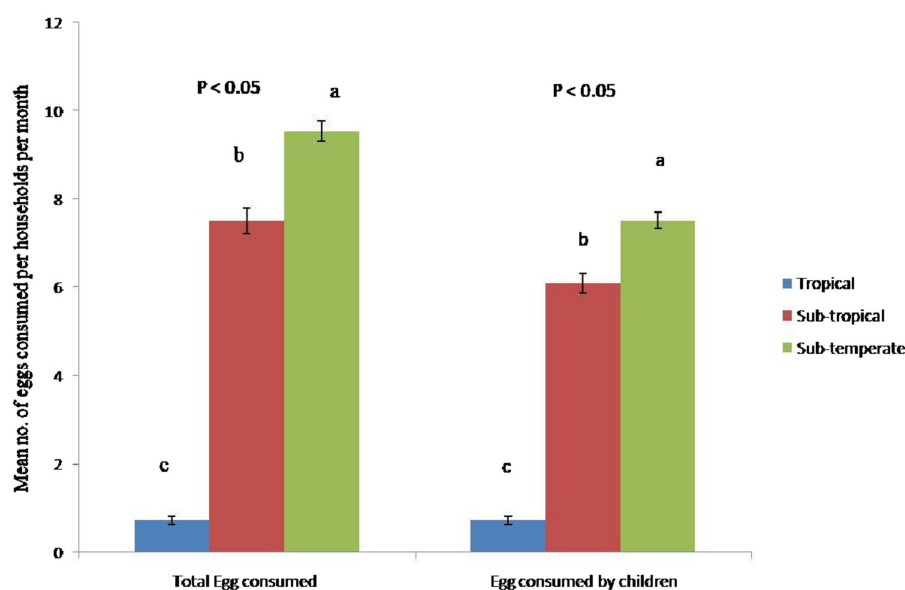


FIGURE 3

The self-reported number of eggs consumed from indigenous chicken by households and children in different agro-ecologies of Indian Himalayan Region. Letter a,b,c denotes significant difference among groups.

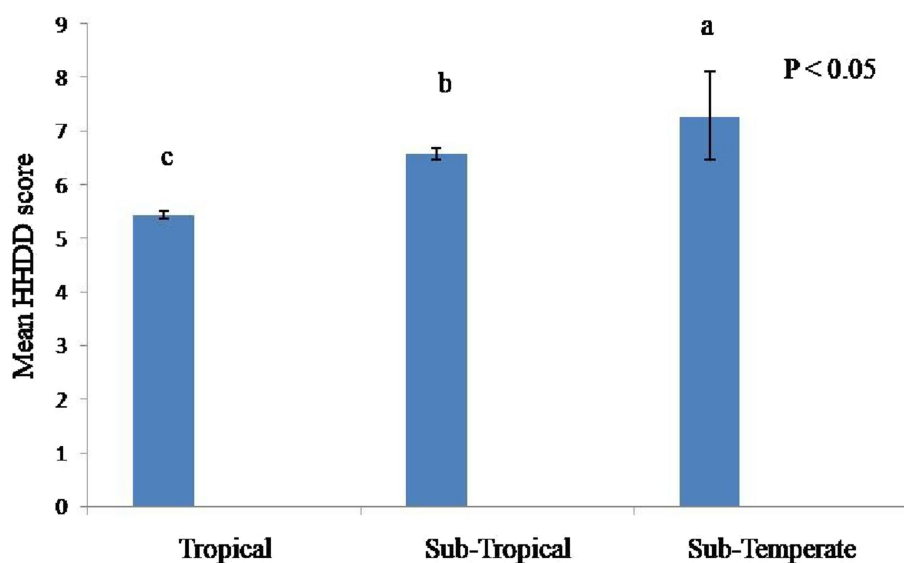


FIGURE 4

Mean households dietary diversity score in three different agro-ecologies of Indian Himalayan Region. HHDS, households dietary diversity score. Letter a,b,c denotes significant difference among groups.

indigenous chicken to express their natural behavior, which enhances their welfare.

The present study found that indigenous chickens are a vital part of traditional communities' food system, particularly in harsh sub-temperate agro-ecology. The larger flock size in sub-temperate agro-ecology translates into higher egg production and higher egg consumption per household, especially by children compared to other agro-ecologies. The HHDS was also higher in sub-temperate agro-ecologies indicating better food security of the households. Similarly, households in sub-temperate agro-ecology sold and

consumed higher numbers of adult birds. Economically, the annual income from indigenous chickens was higher in sub-temperate agro-ecology. In Bangladesh, the rearing of indigenous chickens fetches the highest benefit–cost ratio of 1.71 as compared to commercial broilers (1.22) and commercial layers (1.11) (34). Dumas et al. (18) reported that addressing health and management constraints of indigenous chicken resulted in significant increases in households' income, food security, and physical health of the community. It has been previously noted that the indigenous chicken production system economically empowers rural

TABLE 7 Marketing of indigenous chicken in different agro-ecologies of Indian Himalayan Region.

Characteristics		Tropical climate (n = 235)	Sub-tropical climate (n = 192)	Sub-temperate climate (n = 168)
Purpose of chicken rearing (%)	Self-consumption	11.48	11.45	8.92
	Sale	6.80	2.60	1.78
	Both	81.70	85.93	91.07
Price of adult bird for sale (Indian rupees.)	Cock	500	500	600
	Hen	400	400	450
Price of egg	(Rs.)	10	10	15
Did you get the fair price ^d (%)	Yes	76.92	82.35	98.03
	No	23.07	17.64	1.96
Sale point (%)	Home	41.34 ^a	41.17 ^a	16.33 ^b
	Local market	58.65 ^b	58.82 ^b	83.66 ^a
Whom did you sold ^d (%)	Consumer	76.92 ^b	73.52 ^b	91.50 ^a
	Middleman	23.07 ^a	26.47 ^a	8.49 ^b
Highest demand season ^d (%)	Summer	4.80	2.94	5.22
	Winter	86.53	88.23	84.96
	Rainy	8.65	8.82	19.60

Different superscript in a row denotes significant difference at $p < 0.05$. ^dn = 208 for tropical climate, 170 for sub-tropical climate, and 153 for sub-temperate climate.

TABLE 8 Health and biosecurity measures of indigenous chicken production system in different agro-ecologies of Indian Himalayan Region (%).

Characteristics		Tropical climate (No. = 235)	Sub-tropical climate (No. = 192)	Sub-temperate climate (No. = 168)
Highest mortality in which season (%)	Monsoon	71.1 ^a	68.8 ^a	50.6 ^b
	Winter	26.4 ^b	30.2 ^b	47.6 ^a
	Summer	2.6	1.0	1.8
Do you know NCD (%)	Yes	9.4	9.4	5.4
	No	90.6	90.6	94.6
Did you do the vaccination (%)	Yes	6	7.3	6.5
	No	94	92.7	93.5
Disposal of dead bird (%)	Burial	57	57.3	63.1
	Thrown away	43	42.7	36.9
Disposal of poultry litter (%)	FYM	79.6	81.8	75.6
	No use	20.4	18.2	24.4
Regular contact of birds with children (%)	Yes	81.3	84.9	84.5
	No	18.7	15.1	15.5
Regular cleaning and disinfection (%)	Yes	17	15.6	20.8
	No	83	84.4	79.2
Rodent and wild birds access to Chicken house and feed store (%)	Yes	92.8	88.5	83.9
	No	7.2	11.5	16.1
Hand washing before and after handling chicken (%)	Yes	25.1	14.1	14.3
	No	74.9	85.9	85.7
Isolation of sick bird (%)	Yes	14.5	7.3	5.4
	No	85.5	92.7	94.6

Different superscript in a row denotes significant difference at $p < 0.05$.

communities, regularly supplies the family with readily available animal source food, and generates income (17, 35, 36). Snively-Martinez and Quinlan (37) and Dumas et al. (18) reported that as

the flock size of the household increases and reliable productivity is achieved, the purpose of keeping native chickens shifts to sources of income. Owing to the short generation interval, indigenous

TABLE 9 Constraints to expand indigenous chicken production system in Indian Himalayan Region.

Constraints	Ranking							
	1	2	3	4	5	6	7	8
Predator	188	145	142	85	12	10	8	5
Chicks not available	123	120	115	70	12	12	44	99
Diseases	95	85	80	51	35	80	80	89
Lack of vaccine and medicine	75	70	68	95	92	68	87	40
Inaccessibility to veterinary services	45	40	45	71	111	71	94	118
Feed shortage	43	80	80	87	60	125	81	39
Poor marketing opportunities	20	30	35	80	128	112	97	93
Chicken housing	6	25	30	56	145	117	104	112

Rank 1 = most important, Rank 8 = least important.

chicken production quickly generates income and enhances the socio-economic status of households (17). Self-reliant indigenous chickens can be sold quickly to buy food and cover school, clothing, and medical expenses (28, 35, 38). Native chickens convert scavenging feed resources and kitchen scraps into high-quality protein and these birds do not directly compete with humans for food (5), which is advantageous from a food security standpoint. Hatching percent and chick survivability up to 6 weeks were better in all three agro-ecologies. Desta (3) reported that indigenous hens are excellent mothers, and in this production system, artificial hatchery and brooding facilities are absent.

In the sub-tropical region, the majority of households sold chicken and eggs in local markets, whereas the home and the local market were almost equal sale points for households in the tropical and sub-tropical regions. In the study region, the weekly market operated in a small town, a big village, or a cluster of three to five small villages. Local residents sell agricultural, vegetable, and chicken produce (live chickens and eggs) in these markets (39). These markets attract buyers from outside the regions, mostly traders and businessmen who purchase these items and resell them in major towns at a premium price. There was a higher proportion of chicken and eggs purchased through middlemen in tropical and subtropical regions. In contrast, the majority of sub-temperate households sell directly to consumers. Tropical and sub-tropical regions are better connected to major towns and have a well-developed transportation system, making them accessible to middlemen and traders. In all agro-ecologies, there was a higher demand for indigenous chicken produce in winter and the majority of respondents reported getting a fair price for poultry and eggs. Although there is no clear-cut seasonality of chicken products in the study regions, the higher demand during winter may be because of the festive season, as the majority population is Christian and November to January is the festive season. The fair price may be because of the high demand for meat and eggs from indigenous chickens, because of their suitability to local taste preferences and perceived health benefits (5, 29, 40). Jin et al. (41) reported that the meat of indigenous chicken in Japan fetches two to five times higher prices compared to broiler meat. Also, the marketing chain was short in all the study regions, and households directly sold to consumers, which maximized their profits.

Approximately 9% to 15% of adult birds died in the last year across the three agro-ecologies. Sambo et al. (29) reported higher

mortality in the wet and winter season in native chickens because of infectious diseases. Mortality because of diseases is common in densely inhabited areas where flocks are frequently intermixed, birds are relatively numerous and health prophylaxis and bio-security are least applied. Households have scant knowledge of health and bio-security applicable to chicken farms. The indigenous chickens were in regular contact with family members, especially children, which increased the chance of spreading zoonotic diseases, particularly Salmonella infection (6, 42). Households mostly used poultry litter as farmyard manure. Although high mortality was not reported in the last year in the study area, households reported large-scale mortality in the past among indigenous chickens in the entire village. It was earlier reported that the most common cause of high mortality among village chickens was Newcastle disease (28, 43). During our study, it was also observed that some households reared broilers and improved birds, which might have spread infectious diseases to indigenous chickens. Small-scale chicken growers may choose not to implement bio-security measures because of a lack of awareness of the potential risks or a belief that the benefits do not outweigh the costs (38).

In the present study area, predators, non-availability of chicks, diseases, and non-availability of vaccines were critical production constraints reported by households. Predation is a significant constraint of indigenous chicken production systems, particularly in forest areas, and leads to significant flock loss. Desta (3) argues that as prey animals, indigenous chickens form the local food chain system, and predation is an unavoidable threat. The indigenous chicken production system does not have artificial hatcheries and, for replacement stock, households rely on self-production of chicks. In this system, a hen typically lays eggs then incubates, hatches, and broods the chicks and this cycle takes 105 to 140 days (44) which limits the production of eggs and therefore the number of chicks. Improvement in day-old chick supply to better match farmers' demand would benefit village chicken production (29). Few households reported diseases as the major constraint. Indigenous chickens are hardy, resilient, and evolved in tandem with the production ecosystem (3, 43). In an earlier study, Scherf (45) reported that the Tanzanian chicken landrace "Mwanza" possesses enhanced tolerance to New Castle Disease. However, further studies are needed to substantiate the disease resistance traits of these ecotypes. Feed, marketing, and poultry housing were the least regarded as constraints in the study area by the households. This

indicates the wide range of natural feed resources available in the region.

4.1. Conceptual framework regarding multiple use values of indigenous chicken production system

A conceptual framework illustrating the multiple-use values of ICPS in the study region is depicted in Figure 5. The study revealed that ICPS has multi-functional use values in the study region. It directly contributes to food and nutritional security by providing eggs and chicken meat to households. Chicken eggs and meat are densely packed with nutrients and are a source of animal food. ICPS income is a significant contributor to the total income of households in sub-temperate agro-ecology. Most of the time, this income is used for children's education, family health expenditures, or for the purchase of other food items. As most chickens in the study region are managed by women, this contributes to gender equality in male-dominated traditional societies. ICPS' socio-cultural values include its uses in cultural and social events, gifts, ceremonies, and traditional medicine. ICPS ecological services include genetic diversity, integrated farming systems or mixed farming, manure, nutrient recycling, pest control, wildlife conservation, seed

dispersion, and reducing deforestation. The indigenous food system practiced by communities has evolved over a long period in tandem with the ecosystem change and as a result, is resilient and sustainable.

5. Conclusions and future directions

The present study characterized the indigenous chicken production system in three different agro-ecologies of the Indian Himalayan region. It also evaluated its contribution to the food and economic security of the tribal populations. Indigenous chickens are an important part of traditional communities' food systems, particularly in sub-temperate agro-ecology. The ICPS is an extensive scavenging production system. Households in all agro-ecologies use on-farm production as their primary source of chicken feed. In most cases, women are responsible for poultry rearing, which indicates its role in women's empowerment. The greater size of indigenous chicken flocks and the lower LDI in sub-temperate agro-ecology indicate a greater reliance on chicken for food and economic security. The larger flock size in sub-temperate agro-ecology translates into higher egg production and subsequently higher egg consumption per household, especially by children. The HHDS was also higher in sub-temperate agro-ecology, indicating higher food security of the households.

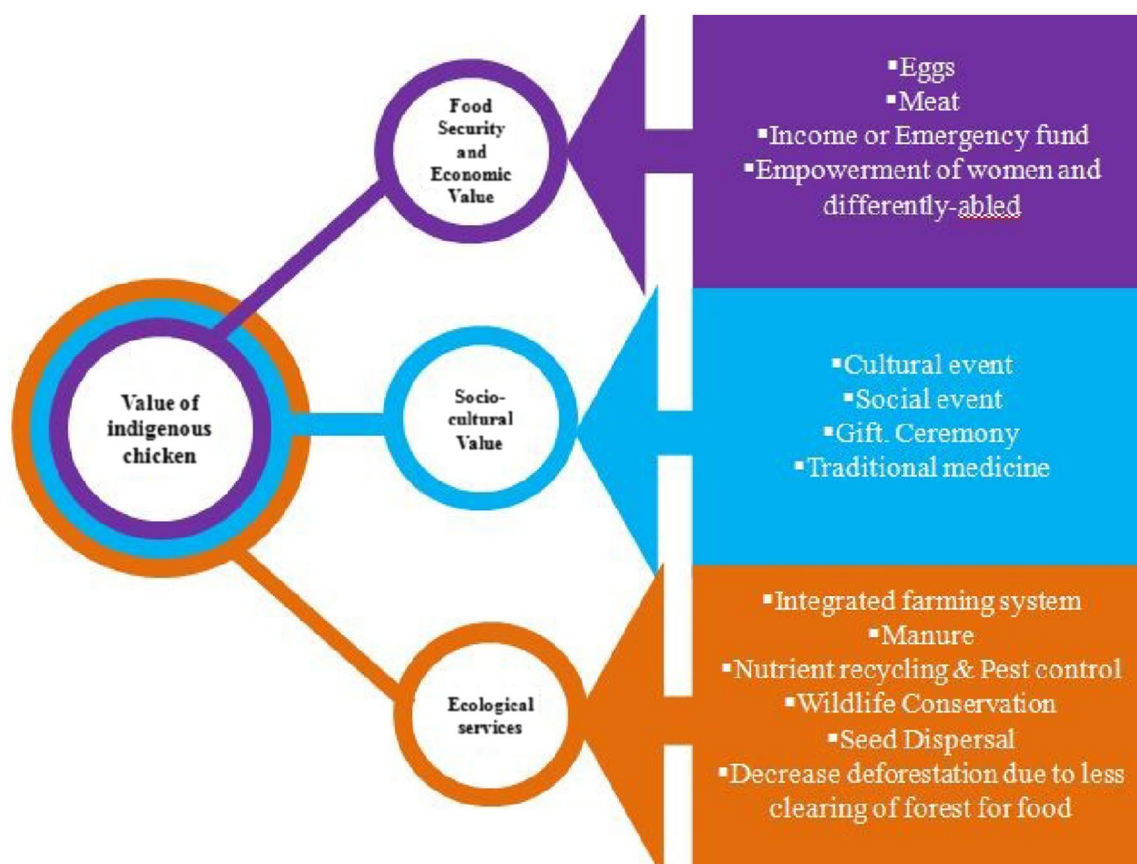


FIGURE 5
Conceptual framework illustrating multiple use values of ICPS in the Indian Himalayan Region.

Economically, the annual income from the indigenous chicken was higher in sub-temperate agro-ecology. In all three study regions, households prefer to rear indigenous chicken mainly because of their adaptability and survivability, meat and egg taste, and scavenging ability. The marketing chain was short in all the study regions and households directly sold chickens and eggs to the consumers, which maximized their profits. Households have little knowledge of health and bio-security applicable to the chicken farm. Predators, non-availability of chicks, diseases, and non-availability of vaccines were critical production constraints reported by the households.

The study indicates the significant contribution of ICPS to the food and nutritional and economic security of traditional communities in the fragile agro-ecologies of the Indian Himalayan Region. Considering its multiple-use values and ecosystem services, there is an urgent need to address its critical constraints to further improve its productivity. Also, the climate-resilient traits and genetic diversity of these ecotypes need to be studied through genomics for future use in specific breeding programs. Policy intervention is needed to prevent the genetic erosion of indigenous chicken genetic resources in these areas due to the introduction of exotic chicken germplasm. Depending on the ecosystem's carrying capacity, some households can be promoted to small-scale semi-intensive ICPS, which will increase incomes and meet growing demand. This will enhance the economy of scale. Furthermore, the health and bio-security aspects of ICPS need to be strengthened to maximize its gains.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The animal studies were approved by Institute Animal Ethics Committee, ICAR Research Complex for NEH Region, Umiam, Meghalaya, India. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed

consent was obtained from the owners for the participation of their animals in this study.

Author contributions

MS, NP, RP, and RM: conceptualization. MS, RY, RK, SDe, and VS: methodology. MS, NP, VS, and JC: formal analysis and investigation. MS, SB, and RP: writing—original draft preparation. MS and SDo: writing—review and editing. MS: funding acquisition. HK and VM: supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The potential consequences of grain-trade disruption on food security in the Middle East and North Africa region

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The Middle East and North Africa (MENA) region has seen remarkable population growth over the last century, outpacing other global regions and resulting in an over-reliance on food imports. In consequence, it has become heavily dependent on grain imports, making it vulnerable to trade disruptions (e.g., due to the Russia-Ukraine War). Here, we quantify the importance of imported grains for dietary protein and energy, and determine the level of import reductions at which countries are threatened with severe hunger. Utilizing statistics provided by the Food and Agriculture Organization (FAO), we employed a stepwise calculation process to quantify the allocation of both locally produced and imported grains between the food and feed sectors. These calculations also enabled us to establish a connection between feed demand and production levels. Our analysis reveals that, across the MENA region, 40% of total dietary energy (1,261 kcal/capita/day) and 63% of protein (55 g/capita/day) is derived from imported grains, and could thus be jeopardized by trade disruptions. This includes 164 kcal/capita/day of energy and 11 g/capita/day of protein imported from Russia and Ukraine. If imports from these countries ceased completely, the region would thus face a severe challenge to adequately feed its population. This study emphasizes the need for proactive measures to mitigate risks and ensure a stable food and feed supply in the MENA region.

KEYWORDS

food, feed, protein, energy, trade, MENA

1. Introduction

The Middle East and North Africa (MENA) region faces significant food security challenges due to limited arable lands and water resources (1), changing dietary habits (2, 3), and ongoing geopolitical conflict (4). All these challenges have been intensified by rapid population growth (5), which has exceeded 2% annually, and is higher than the global average for middle-income countries (1.3%) (2).

The MENA region struggles with a shortage of arable land, having only about 1.07 hectares of agricultural land per person (including 0.16 hectares of cropland per person), which is lower than the global average (0.20) (1). Additionally, the region faces severe water scarcity, with each person having access to only 9 percent of the world average, and in about two-thirds of the

countries, more groundwater is abstracted than is naturally replaced (1). Despite water scarcity, the region has low water prices, due to allocating a significant portion of its resources to water subsidies (amounting to around 2% of GDP), and has an overall water productivity that is only half of the global average (6).

Food security and water scarcity are interconnected challenges in the MENA region (7). Geopolitical issues and insufficient arable land and water resources hinder domestic food production, making the region one of the least self-sufficient in terms of food (8, 9). Climate change makes these issues worse by causing less water to be available overall, increasing temperatures and speeding-up the rate at which water evaporates from the land (10–12).

As a result, MENA is highly dependent on imports (13, 14), especially of grains, where imports account for most of the supply (15). The region is thus highly vulnerable to trade disruptions that limit the global supply of grain and/or increase the price. These disruptions can have multiple underlying causes, including armed conflicts (either locally, as in Syria, or in important exporters, such as Ukraine), pandemics, surges in energy/fertilizer prices, coordinated crop failures across global breadbaskets (e.g., due to extreme events related to large scale droughts or floods) and trade wars.

Recent studies have already highlighted the adverse effects of grain import dependency in MENA (16, 17) and shown that it is expected to increase in the years ahead (18), potentially hindering the region's ability to address its food insecurity. They have also highlighted the region's vulnerability to trade disruptions caused by the war in Ukraine and COVID-19 (19, 20). For example, focusing on stable crops, Al-Saidi (21) has illustrated the varying levels of vulnerability to challenges stemming from these crises, in particular in Lebanon, Libya, Sudan, and Yemen. Furthermore, Ben Hassen and El Bilali (22) emphasized the potentially far-reaching and lasting consequences of conflict-related disruptions to global food and fertilizer markets, and the challenges this poses to the MENA region.

However, to our knowledge, there is a lack of research on the quantitative link between imported grains and dietary energy and protein supply, and therefore on the potential for trade disruption to affect diets. Quantifying this link is complicated by the dual use of imported grains as both human food and as livestock feed for the production of meat, milk and eggs. We address this by determining country-specific values for *per capita* energy and protein consumption that is attributable to imported grains, and assessing the potential impact on diets of trade disruptions. We are thus able to estimate the level of import reductions that would tip whole countries into a state of a severe lack of food.

2. Materials and methods

2.1. Study area

The study area includes the 18 countries that make up the MENA region, which range from low-income countries such as Yemen to high-income oil-exporting countries such as the Arab states of the Persian Gulf. The countries are shown in Figure 1 along with their income class according to the World Bank classification (23). Over the past six decades (2020 compared to 1961), the livestock population (including cattle, dromedaries, sheep and goat) has more than doubled. During this period, meat production (from all livestock) also

witnessed a surge from 1.1 million tons to 11.4 million tons. In the majority of MENA nations, the livestock sector's share of the agricultural Gross Domestic Product (GDP) exceeds 30%, and, in certain countries, it reaches as high as 50%. The average livestock population during the period from 2015 to 2020 is presented in Figure 1.

2.2. Data analysis

The steps taken to address the specified research question are outlined below.

2.2.1. Step 1: examining the sources of grain supply for food and feed sectors - local production and imported grains

Using the Food and Agriculture Organization's (FAO) Food Balance Sheets (FBS) data on total production, export, import, and stock variations, the total domestic supply for each desired grain product was quantified, and the outcomes evaluated according to their allocation information [i.e., Food, Feed, and Other (non-food/industrial, seed and losses); Figure 2; Supplementary Figure 1]. In the case of grain import reductions, our strategy was to prioritize the allocation of imported grain to the food sector. We assumed no changes in both the quantity and the allocation of locally-produced grain. The FAO category 'Other uses' was deducted from locally-produced and imported grain according to its percentage of the total supply.

Data from FAO-FBS on the allocation of the 12 major grain crops in the region (Wheat and products, Rice and products, Barley and products, Maize and products, Rye and products, Oats, Millet and products, Sorghum and products, Soybeans, Rape and Mustard seed, Beans, and Peas) was used to see how grain production (averaged over 2015–2020) in a given country was split between food and feed usage. These grain products cover ~93% of all crop-based feed usage in the region (and, at the same time ~40% of crop-based food usage). We have then broken down the production to different usages (i.e., food vs. feed) using a crop allocation dataset (24, 25).

2.2.2. Step 2: estimating feed demand using livestock production as a basis

In order to calculate livestock feed usage, country-specific data for meat, milk, egg, pork, and mutton production from cattle, sheep, goats, pigs/swine, and chicken for the period 2015–2020 was obtained from the FAOSTAT database (Supplementary Table 1). The production was then apportioned to grid cells based on the FAO's spatially disaggregated livestock-source food supply dataset (26), which gives estimates of the share of production within a country. The dominant livestock production system (LPS) in each grid was then used to determine the total production of each livestock commodity in each LPS. Livestock production in each LPS was transformed into grain fodder and foliage demand via a fraction of grain forage in total feed dry matter and the feed conversion ratio (FCR) (27, 28). FCRs give the quantity of feed (kg-dry-matter) required to produce a given amount of livestock commodity at the herd level (i.e., they consider the need to also feed unproductive livestock,

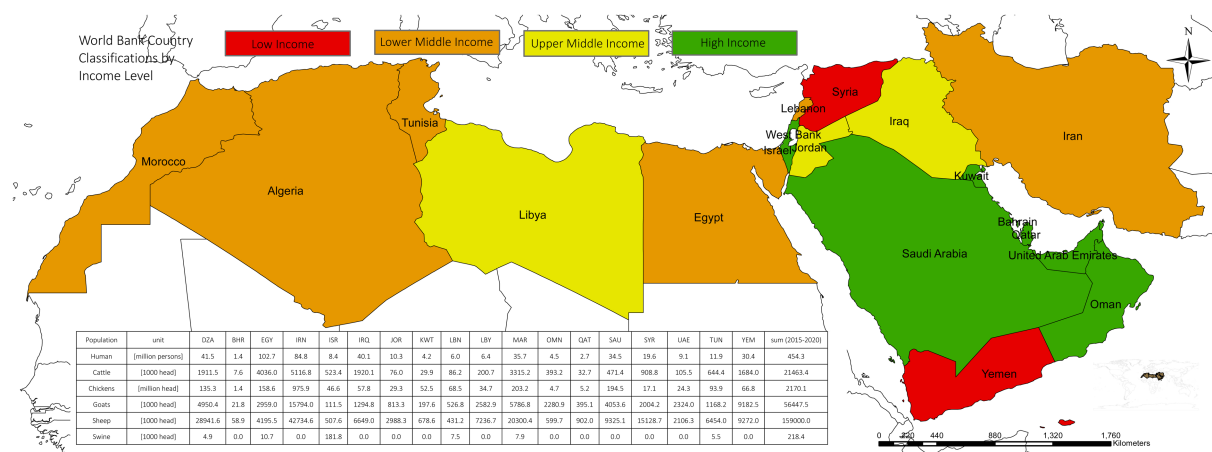


FIGURE 1

Income level classifications of MENA countries (2022–2023) according to the world bank (23). Human population and livestock numbers in MENA countries [average over 2015–2020; (15)].

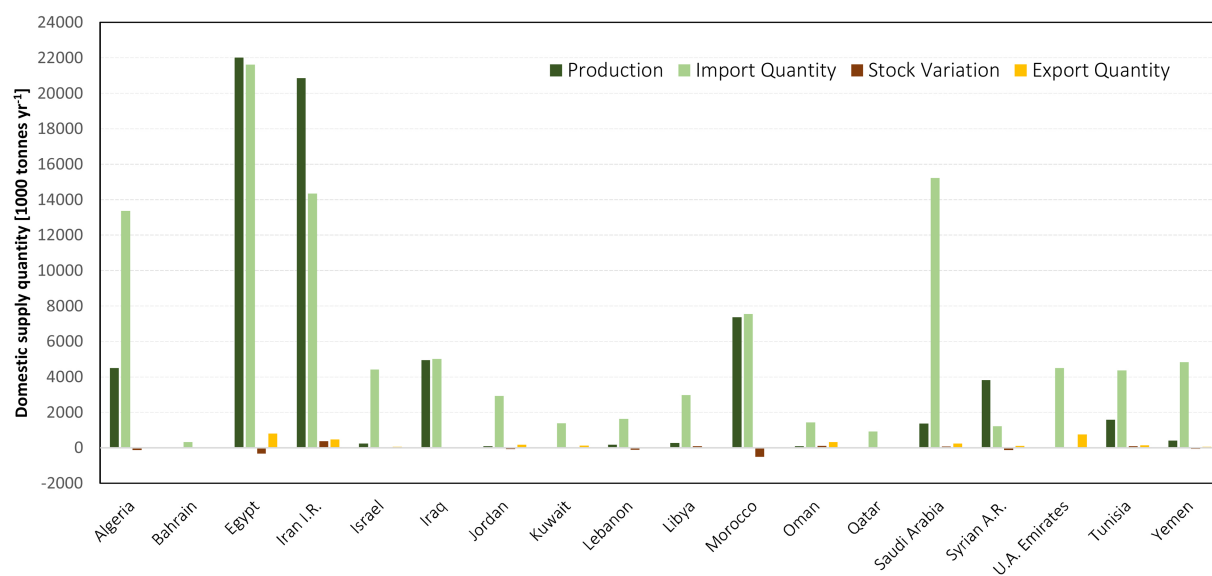


FIGURE 2

Domestic grain supply in MENA countries: insights from 2015 to 2020 FAOSTAT data (15).

such as juveniles; [Supplementary Table 2](#)). This step is important, because in the subsequent stage we will need to backtrack and convert the feed deficit into livestock production.

2.2.3. Step 3: conversion to energy and protein supplies and conducting scenario analysis

Information on the average dietary and nutritional value of each commodity (i.e., kcal/kg food and g protein per kg food; [Tables 1, 2](#)) was calculated to answer the question of what is the role of each food commodity in supplying energy and protein, and also to see how disturbing the balance of the grain trade can affect food and livestock production and consequently protein and energy supplied. For the scenario analysis, we have used the

FAOSTAT trade matrix, the observatory of economic complexity (29), and the united nations commodity trade statistics (UN COMTRADE) (30) databases to obtain grain trade volumes to the region from Russia and Ukraine ([Supplementary Figure 2](#)).

3. Results

3.1. Current import dependency

The MENA region currently consumes 156 Million ton (Mt) of grain for food and feed per year ([Figure 3](#)), of which 68 Mt is produced locally, and 88 Mt. is imported. 94 Mt is directly

TABLE 1 Food energy and protein supply from grain-dependent commodities (2015–2020).

Countries	Food energy supply (kcal/capita/day)	Food energy supply from grain-dependent commodities (share in the total)	Food energy supply from grain-crop-dependent commodities (share in the total)	Food energy supply from grain-livestock-dependent commodities (share in the total)	Food protein supply (g/capita/day)	Food protein supply from grain-dependent commodities (share in the total)	Food protein supply from grain-crop-dependent commodities (share in the total)	Food protein supply from grain-livestock-dependent commodities (share in the total)
DZA (Algeria)	3,430	0.64	0.52	0.12	90	0.83	0.56	0.27
BHR (Bahrain)	3,460	0.55	0.36	0.19	94	0.83	0.33	0.50
EGY (Egypt)	3,336	0.75	0.68	0.06	97	0.85	0.68	0.18
IRN (Iran)	3,059	0.59	0.51	0.08	84	0.77	0.52	0.24
ISR (Israel)	3,561	0.61	0.37	0.24	126	1.16	0.40	0.76
IRQ (Iraq)	2,602	0.55	0.50	0.05	64	0.63	0.49	0.14
JOR (Jordan)	2,663	0.46	0.37	0.09	68	0.62	0.36	0.26
KWT (Kuwait)	3,455	0.64	0.45	0.18	102	0.91	0.41	0.50
LBN (Lebanon)	2,884	0.52	0.42	0.10	70	0.72	0.43	0.29
LBY (Libya)	3,132	0.60	0.48	0.12	83	0.80	0.48	0.32
MAR (Morocco)	3,385	0.71	0.64	0.08	100	0.90	0.68	0.23
OMN (Oman)	2,947	0.53	0.38	0.16	86	0.70	0.33	0.38
QAT (Qatar)	3,459	0.62	0.44	0.17	101	0.88	0.39	0.48
SAU (Saudi Arabia)	3,307	0.63	0.51	0.12	90	0.84	0.48	0.36
SYR (Syrian Arab Republic)	2,822	0.51	0.41	0.10	74	0.64	0.42	0.22
UAE (United Arab Emirates)	3,068	0.56	0.42	0.14	83	0.77	0.42	0.35
TUN (Tunisia)	3,490	0.65	0.54	0.11	100	0.88	0.60	0.28
YEM (Yemen)	2,025	0.46	0.42	0.04	53	0.53	0.43	0.10
Average	3,116	0.59	0.47	0.12	86.84	0.79	0.47	0.33

TABLE 2 Food energy and protein supply from different commodities.

	Commodities	Countries																	
		DZA	BHR	EGY	IRN	ISR	IRQ	JOR	KWT	LBN	LBY	MAR	OMN	QAT	SAU	SYR	UAE	TUN	YEM
Energy (kcal/kg)	Grain crops	3,079	3,167	3,628	3,244	2,959	3,115	2,986	3,969	3,061	3,357	3,002	3,402	3,418	3,349	3,231	2,866	3,416	2,726
	Beef	1,817	1,749	1,528	1,992	1,982	1,482	1,843	2,179	2,061	1,783	1,887	1,896	1,901	2,142	2,695	1,677	1,890	2,666
	Milk	1,206	1,661	815	1,107	599	933	931	2,229	655	1,312	1,115	991	1,777	1,285	768	2,227	782	1,200
	Poultry	1,261	1,269	1,382	1,274	1,264	1,278	1,166	1,482	1,161	1,271	1,224	1,237	1,315	1,272	1,280	1,120	1,233	1,271
	Egg	1,231	1,441	1,421	1,421	1,412	1,423	1,353	1,671	1,284	1,428	1,231	1,414	1,499	1,448	1,420	1,277	1,246	1,422
	Pork	2,701	3,404	2,190	3,681	3,681	3,681	2,623	4,791	3,100	4,106	3,285	4,076	4,232	3,681	3,681	3,982	4,015	3,681
	Mutton and Goat meat	2,039	2,601	2,268	2,440	2,068	2,443	2,273	3,116	2,090	2,346	1,987	2,130	2,725	2,380	2,549	1,748	1,987	2,041
Protein (g per kg food)	Grain crops	128	126	141	127	118	118	134	127	127	139	129	136	124	125	135	119	145	101
	Beef	154	160	146	157	161	135	165	169	156	170	146	159	176	160	143	171	147	140
	Milk	68	103	50	76	44	54	61	121	43	68	78	54	97	87	41	114	46	92
	Poultry	112	129	128	130	151	133	131	126	131	130	126	126	127	131	133	124	135	130
	Egg	104	110	107	107	114	107	111	107	107	107	104	108	109	109	107	108	105	107
	Pork	146	117	124	124	97	124	124	111	131	152	183	116	115	124	124	137	124	124
	Mutton and Goat meat	133	135	144	139	133	139	138	135	143	141	136	137	135	141	137	137	136	148

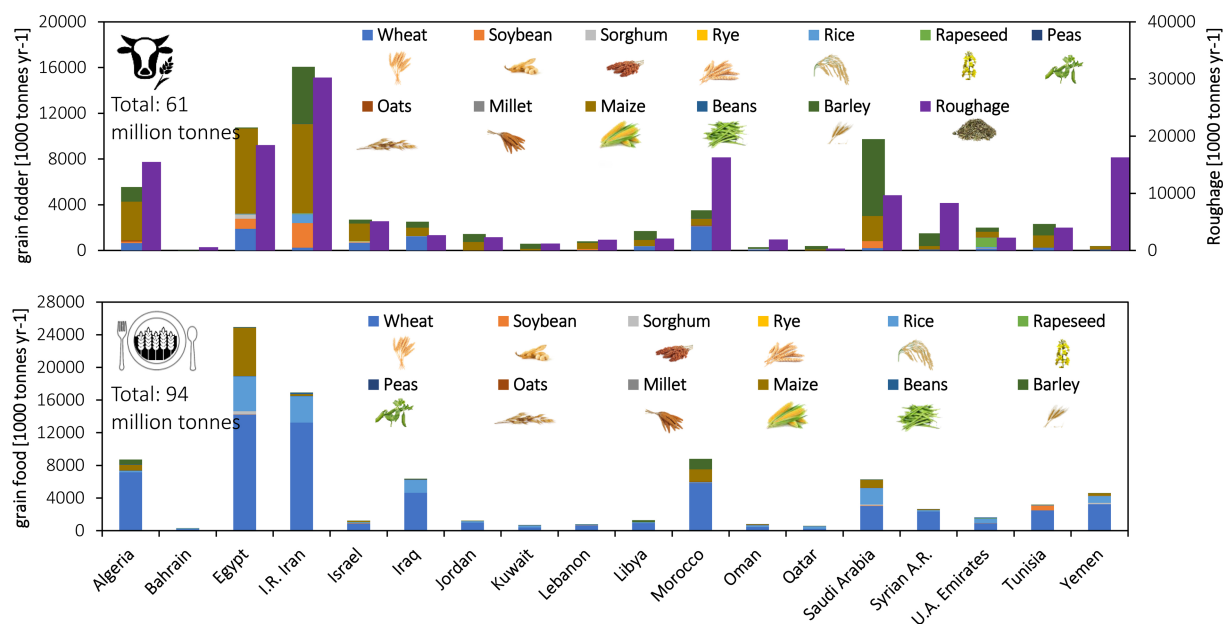


FIGURE 3
Grain utilization for food and fodder in MENA countries: 2015–2020 analysis.

consumed by humans, predominantly wheat (62 Mt), and the remaining 61 Mt. is fed to livestock, predominantly maize (28 Mt) and barley (20 Mt; Figure 3). Grains are particularly important for livestock production due to the importance of poultry in the region (poultry meat and eggs make up 29% of livestock production and consume 74% of total grain usage in the livestock sector) and constitute 33% of daily protein intake by weight and 12% of energy intake (compared to a global average of 31 and 15%; excluding offals, butter, and fat). Imports comprise 45% of food and 74% of feed (Figure 4).

The import dependency of individual countries is heterogeneous and can be split into three broad categories: (1) Syria (10% imported) and Iran (37%) rely primarily on domestic production; (2) Egypt (41%), Iraq (42%), and Morocco (44%) import approximately half their grains; and (3) The remaining 11 countries import the majority of the grain they consume. This includes relatively wealthy countries such as Bahrain, Kuwait, UAE, and Qatar, which are almost entirely dependent on imports, but also poor countries such as Yemen (Figure 1).

The vulnerability to trade disruption depends not just on the import ratio, but also on the grain dependency of diets and to what extent current diets exceed minimum requirements for energy [1,800 kcal/capita/day (31)] and protein [60 g/capita/day (32)] consumption. Across the MENA region, 59% of total dietary energy (1,832 out of 3,116 kcal/capita/day) and 79% of protein (69 out of 87 g/capita/day) is derived from grains, meaning 40% of energy and 63% of protein are from imported grains. Again, the region is heterogeneous. At current import levels, Yemen, on average, only just receives the daily minimum dietary requirements (2,025 kcal/capita/day and 53 g-protein/capita/day) and has a high grain dependency (92%), while Iran produces 63% of its grain demand.

3.2. Impact of grain-trade changes on food security

Reducing grain imports to the MENA region will affect energy and protein supply differently, depending on how the impact is shared between the food and feed sectors. Our assumption is that food is prioritized, meaning that even small import reductions have a large effect on the livestock sector. Thus, dietary protein would fall faster than energy for small reductions in imports due to the importance of livestock for protein (Figure 5). With increasing import reductions, there comes a point at which the livestock sector may no longer receive imported grains, and further reductions fall exclusively on the food sector, resulting in a rapid decrease in dietary energy.

The level of import reduction at which the average energy or protein supply *per capita* falls below the minimum requirements varies between countries (Figure 5). For Yemen, dietary protein is already below the minimum, and dietary energy would fall below the minimum in the case of an 18% import reduction. On the other hand, Syria's remarkable domestic grain production means that even if imports were reduced to zero, sufficient dietary protein and energy would remain available. Other countries fall between these two extremes, with, for example, Jordan falling below the minimum level for protein/energy at a 32/85% reduction and Oman at a 57/86% reduction. However, it should be noted that comparing the average dietary energy/protein to minimum requirements is a very conservative estimate for the point at which a country experiences severe food shortage. Due to the unequal distribution of food supplies, a large fraction of the population will experience shortages well before this point.

The actual impact of trade disruption on diets in the MENA region will also depend on the mitigation steps taken within each country. For short-term disruption, depleting grain reserves could

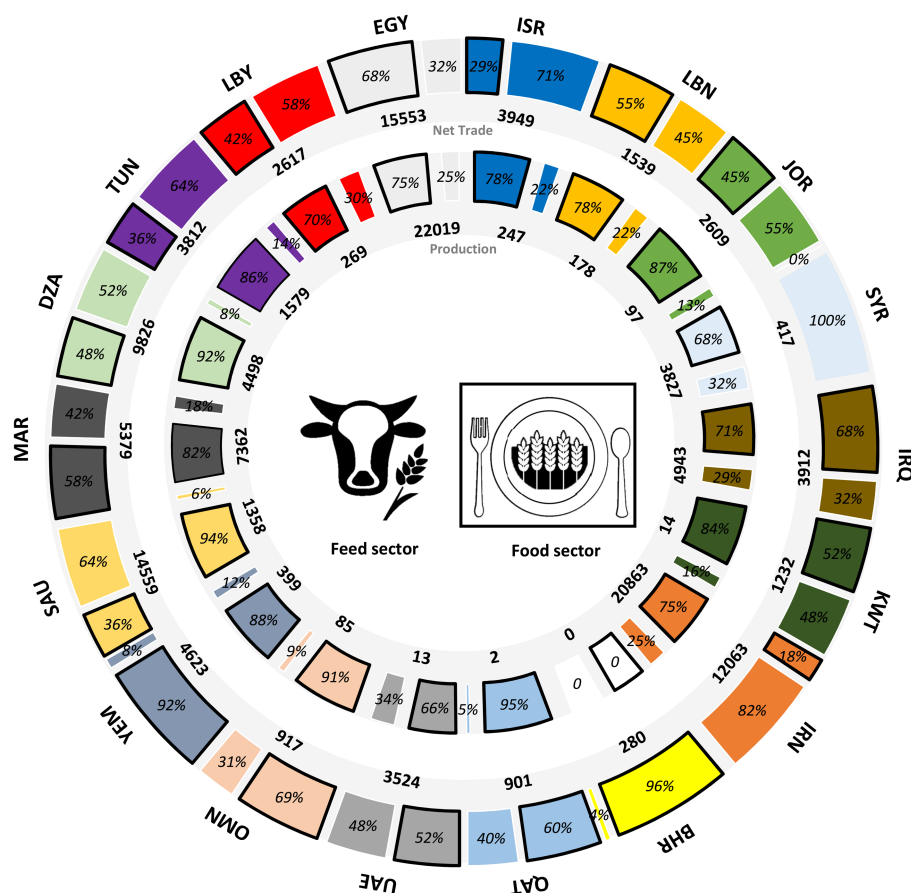


FIGURE 4

The allocation of the net grain trade and local production per country to the feed and food sectors in the MENA region; averaged over the 2015–2020 period (All numbers are in 1,000 tons).

allow diets to be maintained. However, the region as a whole has only 64 Mt. of reserves, equal to 73% of yearly grain imports. *Per capita* grain stock is estimated at 131 kg per person per year, ranging from 36 kg per person in Yemen to about 285 kg per person in Saudi Arabia (Supplementary Table 3). For longer-term reductions in import availability or affordability, adaptation would soften the impact on diets. However, lack of good quality arable and grazing land due to water and other constraints would limit the ability of most countries in the region to considerably increase domestic production. More drastic adaptations, such as large-scale emigration, would negatively affect people within the region and potentially on a broader scale.

3.3. Possible consequences of the Ukraine war

Russia and Ukraine are both large grain exporters and were in 2015–2020 responsible for 34% of imports to the MENA region (17% from each; Supplementary Figure 1). In the case of a complete loss of all imports from Russia and Ukraine, and assuming no substitution from elsewhere, dietary protein in MENA countries would be reduced by 11 g/capita/day and dietary energy by 164 kcal/capita/day. This would be sufficient to tip Lebanon and Yemen 51 and 47% below the minimum protein requirements, even in the case of only Ukrainian grain being unavailable. There would also be severe consequences for

Israel, Libya, Oman, and Tunisia, which would approach the minimum dietary requirements, potentially leading to a large fraction of the population experiencing severe hunger (Table 3).

Finally, it should be remembered that grain import reductions may either be accompanied by a decrease in domestic supply (for example, due to an increase in energy/fertilizer prices), or may cause a drop in domestic supply by sparking armed conflict. In either case, dietary protein/energy availability would take an additional hit, further pushing countries toward the precipice of severe food shortages. For example, one of the short-term causes of the Arab Spring of 2010–2013 is widely believed to be a sharp rise in food prices (33), and the resulting civil wars in Syria and Libya significantly reduced domestic grain production (34). This study shows the vulnerability of the region to reductions in grain imports. Possible mitigation actions would be to build up stocks, reduce the dependency on animal-derived food and to diversify the source of imports.

4. Discussion

The MENA region heavily relies on grain as a significant source of calories and protein for its population. This dependence on grain imports poses a risk to domestic food security, as disruptions in grain trade can lead to reduced availability of calories and protein, potentially pushing some MENA countries below the minimum *per*

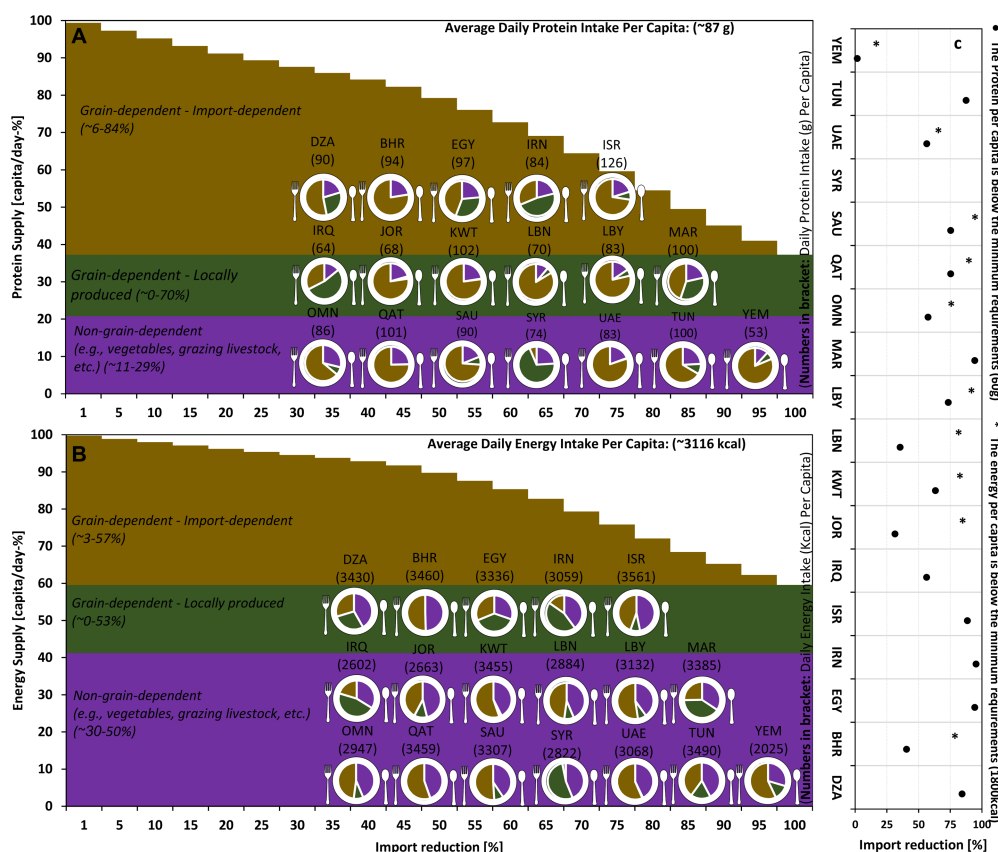


FIGURE 5

Possible consequences of change in total grain import to the MENA region on supplied protein and energy *per capita* per day as compared to the 2015–2020 average. c: % of import reduction at which dietary protein (*) and energy (*) fall below the minimum *per capita* requirement.

capita requirements. Disruptions in exports from the Black Sea region, along with elevated prices, might accelerate the ongoing critical food situation in these regions.

Strategies for reducing the region's vulnerability to trade disruptions are country specific, and depend on the country's current reliance on imported grain, as well as logistical complexities. Possible strategies include trade control and diversification, subsidizing domestic agriculture, fostering international cooperation and aid initiatives, as well as establishing collaborative mechanisms within the region (21).

Our study is part of a growing body of literature that has begun to investigate the impact of trade disruptions on food security, often motivated by the Russian-Ukrainian war and the COVID-19 pandemic. Previous studies predominantly focused on price dynamics in specific regions [e.g. (35, 36)] or developed indicators for the vulnerability of regions to trade shocks [e.g. (37)]. For example, Prantner and Al-Naggar (38) investigated the consequences of the Ukraine-Russia conflict in Yemen and warned that, given the current circumstances, an extended food crisis and potential suspension of humanitarian aid could endanger the survival of millions. Abay et al. (13) classified countries into 10 risk categories, with a particular focus on the short-term impact of crises on regional and national food security. Our results are qualitatively similar to these findings.

However, our research diverges from earlier investigations in two critical aspects. Firstly, we provide a quantitative assessment of the repercussions of trade disruption on both the food and feed sectors,

and the resulting reductions in dietary energy and protein consumption. Secondly, our study offers a regional overview of the entire MENA region, which allows countries individual circumstances to be put in a regional context, and highlights possibilities for collaboration.

5. Conclusion

The recent global food crisis, whose origins include higher costs of essential resources such as fuel and fertilizers, climate change, COVID-19 and conflicts, has hit many countries hard. This includes many countries in the MENA region, some of which were already facing critical food shortages.

Here we have quantified the extent to which MENA countries rely on imported grains, both in general and from Russia and Ukraine in particular. This included determining the importance of imports for energy and protein supply, and identifying at what level of import reduction countries may face severe food shortages. The country-specific analysis shows strong variation in the vulnerability of different MENA nations to import reductions and provides a starting point for understanding how adaption and mitigation measures could make the region more food secure.

It would be valuable in future work to analyze the food-feed system in the MENA region dynamically, considering how economic and societal drivers could spur adaption to reductions in the quantity of imported grain. For example, via increasing the quantity of imported animal

TABLE 3 Potential energy and protein loss (%) due to complete loss of all imports from Russia, Ukraine, and both.

Countries	Potential loss due to complete loss of all imports from Russia		Potential loss due to complete loss of all imports from Ukraine		Potential loss due to complete loss of all imports from Russia and Ukraine	
	Protein (%)	Energy (%)	Protein (%)	Energy (%)	Protein (%)	Energy (%)
DZA	0.31	0.13	1.99	0.81	2.30	0.94
BHR	0.13	0.05	1.17	0.51	1.30	0.57
EGY	5.38	2.03	5.38	2.03	10.75	4.06
IRN	3.73	1.31	2.90	1.02	6.63	2.32
ISR	6.92	2.88	21.65	8.39	28.57	11.28
IRQ	0.03	0.01	0.05	0.02	0.09	0.03
JOR	8.94	2.82	3.83	1.21	12.76	4.03
KWT	3.31	1.45	1.47	0.64	4.77	2.09
LBN	21.96	8.02	36.15	17.17	58.11	25.19
LBY	5.02	2.12	13.54	5.72	18.56	7.84
MAR	2.45	0.94	7.03	2.70	9.48	3.65
OMN	11.92	5.95	2.24	1.12	14.17	7.07
QAT	1.54	0.63	1.55	0.64	3.09	1.27
SAU	4.57	1.76	3.94	1.52	8.51	3.28
SYR	1.60	0.70	1.11	0.49	2.71	1.19
UAE	2.94	1.18	1.12	0.45	4.06	1.63
TUN	1.62	0.67	11.45	4.71	13.07	5.38
YEM	23.65	12.26	15.91	6.25	39.57	18.51

products, conversion of suitable grazing land to arable production or reduction in food waste. Alternatively, the effect of trade disruptions on the food supply could be amplified if they lead to economic collapse, for example due to civil war. The ability of countries to adapt will critically depend on the strength and duration of trade disruptions, as well as economic and societal factors, land availability and government policies.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Author contributions

JR and AS conceived and designed the study. JR pre-processed the data and performed the analyses. JR wrote the first draft with support from AS while HM, MK, and KB-B contributed to improving the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2023.1239548/full#supplementary-material>

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Pilot study of a digital literacy-based intervention to confront concomitant crises amongst key food system actors in Chile

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Introduction: The fragility of food systems in Chile has been exposed through concomitant crises, from a social crisis in 2019 to the COVID-19 pandemic, and ongoing climate change. There is an increased dependence on information and communication technologies (ICTs) to produce, sell, and consume food and the digital divide has increased. The lack of digital literacy in Chile has not been evaluated or considered within comprehensive interventions.

Methods: To examine how local food systems can be strengthened, we conducted a pilot study of a digital literacy-based intervention with smallholder farmers, vendors, and consumers ($n = 96$) of different age groups (25–45 y, and 46–65 y) from adjacent urban and rural regions in Chile. Telephone surveys were carried out on the use of ICTs, access to the food environment, and agricultural practices during crises. A 5-week digital literacy intervention was carried out on digital confidence, the use of ICTs to generate networks, networks, the use of apps to sell or buy food, banking operations, and communication with state agencies. We also planned a virtual conversation about the food system and nutrition in Chile.

Results: All participants knew how to read and send WhatsApp messages but >50% of farmers and vendors reported cell signal problems. Between the 2019 social crisis and the COVID-19 pandemic, supermarkets as the main source of food decreased from 79 to 57%, and delivery increased from 2 to 17%. In total, 92% of the participants received the intervention, and 52% expressed satisfaction. Across participants, the average implementation score was 61%. Only one person connected to the virtual conversation.

Discussion: Crises have impacted how the Chilean population in both urban and rural regions navigate their food environment for their household as well as small-scale agricultural production in these areas; elucidating a greater dependency on ICTs amongst small-scale farmers, vendors, and consumers in Chile to buy and/or sell food. We also conclude that it is feasible to implement a digital literacy intervention for key food system actors in urban and rural settings in Chile. Future studies will contribute to the evidence base about the feasibility and impact of similar digital literacy interventions; an area of increasing importance given the rising prevalence of the digital food environment worldwide.

KEYWORDS

food systems, digital literacy, concomitant crises, Chile, COVID-19, climate change

Introduction

Ongoing climate change together with the COVID-19 pandemic have exposed vulnerabilities in both local and global food systems (FAO, IFAD, UNICEF, WFP, and WHO, 2022). In the case of Chile, a social crisis that started in October 2019 led to the damage of many supermarkets, some of which remained closed during the COVID-19 pandemic. This, together with ongoing climate change, has had an impact on the Chilean food system, making its fragility visible (Kanter and Boza, 2020). These concomitant crises are superimposed on the existing challenges of obesity, undernutrition, and climate change; referred to as the global syndemic (Swinburn et al., 2019). The COVID-19 pandemic highlighted the importance of the digital food environment, or the digital aspects of food environments that include both digital sectors (e.g., digital food sales) and actors (e.g., public and private entities) that interact in digital settings (e.g., smartphone applications, social media) (Granheim, 2019). The digital food environment, in Chile and globally, has exacerbated the digital divide by pushing many to depend on information and communications technologies (ICTs) to produce, sell, and eat their food and excluding those that lack digital literacy or ICT access. The UN Educational, Scientific and Cultural Organization (UNESCO) defines digital literacy as “a set of basic skills which include the use and production of digital media, information processing and retrieval, participation in social networks for creation and sharing of knowledge, and a wide range of professional computing skills” (Karpati, 2011, p. 1). Digital tools, or ICT, can strengthen local food systems by (1) informing consumers about healthy and sustainable diets to motivate behavior change and; (2) facilitating linkages between food demand and supply (Todorovic et al., 2018). However, how to improve digital literacy for agriculture and food systems actors is largely ignored (World Bank, 2017; Trendov et al., 2019). The impact of digital literacy on strengthening food systems has not yet been evaluated in Chile, nor have comprehensive interventions been proposed in this regard.

In Chile, smartphone use became common in the general population relatively early compared to other Latin American countries, such that by 2010 there was on average more than one mobile cellular subscription per inhabitant (World Bank, 2022). Studies prior to the COVID-19 pandemic suggest that small-scale producers did not use online services for business-related purposes, such as online banking, sales, purchase of inputs, or carrying out administrative procedures with public institutions (Boza et al., 2018, 2019). The strict COVID-19 lockdown measures in Chile, which led to farmers market closures, prompted an increased demand for the delivery of fresh products (Boza and Kanter, 2021). The global impact of COVID-19 exacerbated the dependence on the digital food environment in Latin America and elsewhere, even with great diversity in the makeup of local food systems within and between countries (O'Meara et al., 2022). Commonalities have been observed in the way that food systems of different countries dealt with COVID-19, both in its impacts and in its adaptation and resilience strategies, which suggests that this pilot study may be useful for other countries.

Leading up to the COVID-19 pandemic, small-scale producers in Chile were not taking advantage of how digital tools could help them in their value chain (Klerkx et al., 2019). The subsequent ramifications of this limited the promise of small-scale producers in Chile to contribute to the expanding digital food environment through greater sales of fresh products. A better understanding of digital literacy

amongst key food system actors in Chile will provide insights as to how to strengthen food systems through digital means. Therefore, from 2022 to 2023, we conducted a virtual study to pilot a digital literacy intervention amongst key food systems actors in the adjacent Metropolitan and O'Higgins regions of Chile, where there is a high adult obesity prevalence and where fresh food provision, especially fruits and vegetables, is concentrated (Boza et al., 2020). This approach addresses the limitations of previous studies that have not specifically examined digital literacy amongst food system actors for the purpose of food systems strengthening.

The primary aim of the pilot study was to assess the feasibility of implementing a digital literacy intervention amongst three key actors from Chilean food systems: small-scale farmers, farmers market vendors, and consumers. The secondary aim of the pilot study was to identify how the fragility of food systems in Chile has manifested itself during concomitant crises (social, COVID-19, climate change) and elucidate trends in the usage of information and communication technologies (ICTs) to produce, sell and consume food. Thus, the purposes of this article are: (i) to present how key food systems actors in Chile have utilized ICTs between 2019 and 2021; (ii) to present the core components of the digital literacy intervention; (iii) to present strategies used in its pilot implementation; and (iv) to discuss lessons learned during the implementation and evaluation of the pilot study, and share implications for subsequent digital literacy interventions globally. The present study is unique in that its focus is on digital literacy, rather than ICT utilization, and the importance of tailoring a digital literacy intervention based on food system actor group and area (urban/rural); enabling a better understanding of how to implement digital literacy interventions for local food systems strengthening.

Evidence before this study on the role of ICT and food systems

We searched PubMed for any study published up until 28 July 2023 using the search terms “ICT” or “Information and Communication Technologies” and “food systems” which yielded six results; of which three were relevant to this study. Samoggia et al. have conducted a systematic review of “digital technologies in the agro-food sector” in which they concluded that “Apps” are the most prevalent digital technology within the agro-food chain, especially within the production, distribution, and consumption sectors (Samoggia et al., 2021). In China, in response to the COVID-19 pandemic, Zhan and Chen highlight the important role that ICTs played in keeping the food supply chains operating as normally as possible, from virtual technical support to agricultural producers, to virtual events to connect all the actors in the food supply chains, and digital applications for e-commerce that included contactless delivery services (Zhan and Chen, 2021). In the third paper, MacKenzie and Davies describe the co-design of an online sustainability impact assessment (SIA) framework called SHARE IT with the purpose of disseminating “ICT-mediated food sharing initiatives” and their subsequent impacts on urban food systems, especially in terms of its contribution to the sustainability of said systems (Mackenzie and Davies, 2019). In this context, food sharing is defined as activities around food that are not limited to eating or drinking together, such as community gardens, community kitchens, and redistributing food

products to those in need; of which websites, apps, and social media platforms are becoming the common means to promote food sharing initiatives (Mackenzie and Davies, 2019). On the Share City website, one can search a database of such initiatives and register a food-sharing initiative, and undertake a related sustainability assessment if desired (ShareCity, 2023). All three of these studies highlight the myriad positive contributions ICT has brought to food systems that can be applied to different contexts globally. However, none of these three articles mentioned digital literacy and thus, presume that the users and beneficiaries of said ICTs within food systems have the level of digital literacy necessary and sufficient to utilize the given ICT.

A second PubMed search for “digital literacy” and “food systems” resulted in only one new (2023) study on the multi-faceted role that Facebook has played in strengthening how small farmers in Myanmar do business (Faxon, 2023). While this work was funded through a grant from “Facebook Research on digital literacy, demographics and misinformation in Myanmar,” digital literacy, or literacy alone, is not mentioned in the body of the text itself (Faxon, 2023). These studies suggest that food systems actors can benefit from ICT use through online videos, apps, and different social media platforms that greater digital literacy can help facilitate. Digital literacy is not limited to solely the literal use of ICT nor its production (e.g., the Share City website) as both the user and the beneficiary process its respective information, and in the case of social media, participate in social networks to both create and share knowledge (Reddy et al., 2020). Thus, a greater focus on education around digital literacy competencies is warranted to ensure that the maximum positive benefit and reach of ICTs within food systems is achieved and that they do not exacerbate the current digital divide that still exists in many countries (Reddy et al., 2023). Taken together, digital literacy is important because it improves the utilization of ICTs which in turn can help strengthen food systems through different impacts throughout the agri-food chain.

Methods

Study setting and sample

The study was conducted in two adjacent regions in the center of Chile: the more urban Metropolitan Region where over half of the Chilean population resides and the capital, Santiago, is located, and the rural Region of O'Higgins. The region of O'Higgins has one of the largest rural populations in Chile and an economy heavily dependent on agriculture that together offers important socio-demographical contrasts compared to the Metropolitan region (Rengifo et al., 2022). While both regions have a high prevalence of adult obesity, more school-age children are obese in rural areas than those in urban areas (JUNAEB -Ministerio de Educación, 2023). The region of O'Higgins has one of the greatest proportions of employed men and women in the agricultural sector (21.4%) of Chile's 16 regions, while the Metropolitan region has one of the lowest (1.8%) (ODEPA, 2023). However, the predominance of seasonal agricultural work in the O'Higgins region has led to one of the country's highest unemployment rates for contract (non-salary) workers. Thus, O'Higgins is one of two regions in which, independent of an average educational completion of 12 years, the majority of employed people are located in vulnerable areas and with an average income that does not exceed 1.5 times the

minimum wage (Municipalidad Rancagua, 2018). While the Ministry of Agriculture has designated many places within both regions as agricultural emergency areas due to drought, extreme weather events have a greater impact on the O'Higgins region related to the aforementioned characteristics (MINAGRI, 2023). Given these socio-demographical contrasts between the O'Higgins and Metropolitan regions, the proximity between the two in turn motivated the selection of these two regions for the study setting. The study sample was designed to include 96 participants stratified by region ($n=48$), by actor (small farmer, vendors, and consumers), and by age group (25 to 45 years and 46 to 65 years) and sex to provide a pilot size sample sufficient to assess the feasibility and acceptability of a digital literacy intervention. Overall, for each category of region, actor, age group, and sex four participants were included if they reported residing in the specified region, defined themselves as being a small farmer, food seller, or consumer, and was between the ages of 25 and 65. Participants were recruited through word of mouth and invitations to participate that were also published on social media.

Baseline data collection

Knowledge of participants' baseline levels of digital literacy and use (or lack thereof) of different digital platforms was essential for the design of the digital literacy intervention described below. Therefore, we collected survey data from all participants on socio-demographic characteristics, use of information and communication technologies (e.g., cellular phones), food environment access, and food insecurity, specifically the Spanish version of the food insecurity experience scale (FIES) for COVID-19 household reference version (FAO, 2020). The food environment access survey included 14 questions about how all participants accessed food for their household during three different time periods: (i) before the social crisis in October 2019, (ii) during the social crisis, and (iii) during the COVID-19 pandemic, with specific questions about their local farmers market and the use of social media to obtain foods during the COVID-19 pandemic. From the participants who self-identified as small-scale producers (i.e., farmers) we also collected survey data on agricultural practices during these same three time periods. Many of the 23 survey questions were categorical and asked about their agricultural production and related costs, interaction with intermediaries, and needs for technical assistance. Due to the digital objective of this study, all surveys were designed to be implemented through a conversation via cellular phone. A trained research assistant in public health nutrition conducted all surveys in Spanish between March and October 2022. All survey instruments have been previously validated in Chile (Boza et al., 2019) or in Latin America (Kanter et al., 2014; Rubinstein et al., 2016; FAO, 2020).

Digital literacy intervention design

Based on how digital tools might benefit a food system actor differently, the digital literacy intervention was designed separately for small-scale producers, vendors, and consumers. To design the digital literacy intervention, five key competencies were defined based on the statistical analysis of the telephone survey data described below and previous studies related to digital literacy, especially in Latin America,

which considered the COVID-19 pandemic (Ministerio de Educación y Cultura and Centro MEC, 2010; Hargittai and Dobransky, 2017; Letelier Loyola, 2019; Sunkel and Ullmann, 2019; NU. CEPAL, 2020; OEA and Twitter, 2021). The first key competency was digital trust (i.e., virtual connectivity, data protections, and digital identity) with a sub-competency of being able to use ICTs to search for information. The second key competency was the frequent use of information technologies for communication and networking (e.g., through WhatsApp, email, Facebook, Instagram, other social media platforms and Zoom) with a sub-competency specifically about how to use Zoom. The third key competency for the small-scale producers and vendors was sales networking using WhatsApp communities and a sub-competency on “WhatsApp Business.” For consumers, the third key competency was on how to use applications to purchase food (e.g., Uber Eats, Cornershop). The fourth key competency was about how to do banking operations using ICTs (e.g., viewing monthly statements, bank transfers, communicating with the bank, etc.). The fifth key competency was how to use ICTs to communicate with state entities (e.g., the Institute of Agricultural Development of the Ministry of Agriculture (INDAP) – for farmers, how to emit an electronic receipt for vendors, and the National Consumer Protection Agency (SERNAC) – for consumers). For each competency, five literacy levels were identified: basic, fundamental, intermediate, advanced, and expert (Table 1) based on the necessary skills of digital literacy (use, communication/interaction, analysis, and creation) as Lee suggests (Lee, 2014). To design the digital literacy intervention, we utilized the study variables collected in the surveys to determine what baseline level of digital literacy each participant had within each key competency. This is described in detail in the following subsection. Each participant received material for the level ahead of their baseline level. For example, if a participant had a baseline level 1 then they received the material that targeted level 2 of the same competency. Because small farmers/vendors had statistically significant differences from consumers related to ICT use, the digital literacy intervention was designed separately for small-scale producers/vendors and consumers, and the materials were tailored to these two groups. Whereby, for each key competency and literacy level, visual materials were separately designed for small-scale producers/vendors and consumers.

Digital literacy intervention

The digital literacy intervention took place between November and December 2022. At the beginning of each week, each participant was sent via WhatsApp the digital visual materials that corresponded to their actor group and key competency for that week. All participants included in the telephone surveys were offered the 5-week digital intervention program. The study procedures and timeline are presented in Figure 1.

Definitions of each key competency level based on the study variables for the digital literacy intervention

Low or no digital trust was defined for farmers and vendors as no digital sales and not using WhatsApp for work purposes or

not using electronic banking whereas no specific variables were used to determine low or no digital trust for consumers. The use of ICTs to search for information was defined for all as those who reported using their phone to browse the internet. The frequent use of ICTs for communication and networking differed between farmers/vendors and consumers. The farmers and vendors with no or low use of ICTs for communication and networking either did not know how to read WhatsApp or use their cell phone to chat or knew how to use their cell phone for WhatsApp, but did not use their cell phone for social media purposes. For farmers and vendors, respectively, frequent use of ICTs for communication and networking was defined as having made digital sales through WhatsApp or having utilized WhatsApp for work or using their cellphone for both WhatsApp and social media while those with more advanced use and skill have utilized any social media platform for digital sales. The consumers with frequent use of ICTs for communication and networking was defined as those who used their cellphone for both WhatsApp and social media compared to those who only used their cellphone for WhatsApp (low communication and networking skills) and those who did not even use their cell phone for WhatsApp (no ICT use for communication and networking). Amongst all participants, because only one person reported using Zoom as a means of using ICTs for communication and networking, it was assumed that all other participants did not know how to use Zoom, especially on a cell phone. For farmers and vendors, we defined sales networking as those that reported using digital platforms, especially WhatsApp, for business purposes, specifically digital sales. Consumers who had reported using apps during the COVID-19 pandemic to purchase food for their household were defined as those with advanced use of these apps, while those that have only had experience using social media platforms to do so (i.e., Facebook, WhatsApp, or Instagram) were defined as intermediate users. Consumers who had not reported using their cell phones to buy food for their household during the COVID-19 pandemic but reported knowing how to use social media platforms were defined as having a basic level of being able to use apps to purchase food compared to those who did not use their cell phone for any social media. Online banking literacy was defined as intermediate where participants had reported using online banking as well as online Bill Pay; as low, when they only used online banking but not online Bill Pay; or none, when they reported neither of these actions. For all participants, ICT use to communicate with state entities was defined either as low if someone reported using email or none for those who did not use email.

Food system dialogue

After the conclusion of the digital literacy intervention, we invited via a WhatsApp graphical invitation all the participants who completed the intervention to participate in a virtual food systems dialogue (FSD), over the Zoom platform, about food and the food system in Chile. The FSD method is a globally validated methodology designed to (a) engage groups who would not normally work together, (b) foster greater agreement and ambition among them, and (c) encourage greater alignment and

TABLE 1 Intervention content and level by food system actor group.

1A: Farmers and vendors					
	Level				
Competencies	Without skills	Basic	Intermediate	Advanced	Expert
1a. Digital trust (connectivity, data protection, digital identity)	Fear and insecurity of technology	Ability to recognize fraud or virtual risks (e.g., scams, malicious emails or links, etc.)	Know and apply protection measures such as double encryption. Know and apply steps to distinguish fake news, malicious sites, etc.	Knowledge of and ability to access information spaces and communication media in virtual format (e.g., electronic newspapers, television channels, others)	Knowledge of and ability to access training and education programs on topics of interest from reliable sources (e.g., Coursera)
Baseline (n)	27	37	0	0	0
1b. Continuous and extensive use of ICTs to search for information	Does not use the Internet to search for information	Knows how to open web pages and enter Google to perform searches	Ability to navigate the Internet and search in search engines	Advanced web searches, with the ability to distinguish safe sites and trusted sources	Expert management of advanced searches in internet search engines
Baseline (n)	20	44	0	0	0
2a. Continuous and extensive use of ICTs to communicate and generate networks (Whatsapp, Facebook, Instagram, etc.)	Does not know how to use apps	Can download social media apps and create a name. Can create an email account	Basic social media app management: can recognize the icon, can enter, navigate. For Whatsapp, ability to send a text and audio message, send videos	Advanced management of the app, interaction with users and publication of content. In the case of WhatsApp, the ability to make video calls	Expert management of social media apps. Interaction with users, publication of content, knows how to report inappropriate content, search for content of interest, others
Baseline (n)	4	15	37	8	0
2b. Use of zoom	Does not know how to use Zoom	Can recognize the Zoom icon, can join and leave a meeting	Can change their name in Zoom, open and close the microphone/camera, send messages to the chat, read chat messages	Can create meetings in Zoom, send an invitation, join groups, and others	Can record and save recording in Zoom, do surveys, and other advanced Zoom functions
Baseline (n)	62	0	2	0	0
3a. Sales networking: Whatsapp communities	Does not know how to use Whatsapp communities	Can download Whatsapp, create a profile and learn the basic uses (add contacts, open a conversation, create a community)	Knows how to configure Whatsapp for administrators and add or remove members. Knows how to deactivate a community and how to add a group to a community.	Knows how to establish security criteria and recommendations for good practices for the community, generates interactions with the members of the community	Knows how to send broadcast messages and organize conversations with labels
Baseline (n)	64	0	0	0	0
3b. Sales networking: Whatsapp business	Does not know how to use Whatsapp business	Knows the costs and benefits of using Whatsapp business	Download Whatsapp Business, create a profile and learn the basic uses (add contacts, open a conversation, send individual messages)	For WhatsApp Business, knows how to apply security measures, end-to-end encryption and others, can send automated messages, generate automatic responses and other similar interactions	Can generate a business profile with relevant information, create a catalog, delete products, generate welcome messages, automatic responses, and others
Baseline (n)	50	0	14	0	0
4. Digital banking (payment and account statement review, use of financial services, transfers, contacting the bank, etc.)	No experience with digital banking	Can enter the bank's website or use the app, with username and password, contact the bank	Can handle basic online banking operations such as knowing account status, balances, etc. Has passwords that allows online procedures	Ability to make transfers, simulate credits, contact an executive	Trust in digital banking, ability to carry out different procedures, communicate with the bank online, etc.

(Continued)

TABLE 1 (Continued)

1A: Farmers and vendors					
	Level				
Baseline (n)	26	7	31	0	0
5. Communication with state-based organizations	Does not have a unique password nor does it use government digital platforms	Manages to provide itself with a unique government password and can use it to access to government services	Has a unique government password, can search the web for government organizations	Can download/request forms, claims or inquiries, carry out simple procedures (e.g., background certificate, etc)	Can download/request forms, claims or inquiries, online tax payments or other similar online interactions (e.g., internal tax services)
Baseline (n)	12	52	0	0	0

1B: Consumers					
	Level				
Competencies	Basic	Skilled	Intermediate	Advanced	Expert
1a. Digital trust (connectivity, data protection, digital identity)	Apply data protection measures such as double encryption and secure locks	Know and apply steps to distinguish fake news, malicious sites, etc.	Learn to select validated sources of information, assuming a critical attitude towards the content that is available on the web	Report malicious sites, fraud, etc.	Use of tools such as antivirus, knows how to use VPN, etc.
Baseline (n)	32	0	0	0	0
1b. Continuous and extensive use of ICTs to search for information	Knows how to open web pages and enter Google to perform searches	Ability to navigate the internet and search in search engines	Advanced web searches, with the ability to distinguish safe sites and trusted sources such as recognition of https and lock symbol as safe	Ability to identify, locate, retrieve, store, organize and analyze the digital information collected in search engines.	Ability to communicate in digital environments, share resources through online tools, connect and collaborate with others through digital tools, interact and participate in communities and networks (for example through platforms such as Google Drive, Dropbox, others)
Baseline (n)	6	26	0	0	0
2a. Continuous and extensive use of ICTs to communicate and generate networks (WhatsApp, Facebook, Instagram, etc.)	Can download apps from social media and create a username	Knows how to use the app and can interact with other users / send and receive emails; interaction via texts and audios	Management of the app, interaction with users, extensive interactions (texts, audio, images, stories, others) and sharing content	Ability to create groups in WhatsApp and other ways to generate networks in social media platforms that are more advanced	Expert management of social media apps. Interaction with users, content publication, critical reflection and ability to report inappropriate content, search for content of interest, ability to create digital content
Baseline (n)	1	5	18	8	0
2b. Use of zoom	Does not know how to use Zoom	Can recognize the Zoom icon, can join and leave a meeting	Can change their name in Zoom, open and close the microphone/camera, send messages to the chat, read chat messages	Can create meetings in Zoom, send an invitation, join groups, and others.	Can record and save recording in Zoom, do surveys, and other advanced Zoom functions
Baseline (n)	31	0	1	0	0

(Continued)

TABLE 1 (Continued)

1B: Consumers					
	Level				
3. Continuous and extensive use of apps to buy food (e.g., UberEats)	Download apps, create username and search for food	Knows how to use the app, pays with cash, knows how to perform a search to order food, direct contact with vendors (e.g., Facebook Marketplace)	Knows how to use the app, knows and uses different payment methods such as cash and credit/debit cards, etc.	Advanced management of the app as a consumer, manage simple purchases through delivery apps, such as the ability to place an order from 1 supplier	Advanced management of the app as a consumer, manage various purchases through apps, ability to make purchases in various items (not exclusively food, for example pharmacies or others)
Baseline (n)	1	5	18	8	0
4. Digital banking (payment and account statement review, use of financial services, transfers, contacting the bank, etc.)	Handles basic operations such as checking account status, balances, etc.	Has a card or another that allows secure online procedures (Digipass, transfer card, etc.)	Ability to make transfers, simulate credits, contact an executive	Confidence in digital banking identity, ability to carry out different procedures, communicate with the bank, others	Link the bank account with other apps, automate bill payments, synchronization with other apps, etc.
Baseline (n)	3	1	28	0	0
5. Communication with state-based organizations	It does not have a unique password and uses government digital platforms without the need for a unique password	It manages to provide a unique password and access to government services that require a password	Download/request forms, claims or inquiries, carry out simple procedures (eg background certificate, others)	Download/request forms, claims or inquiries, online tax payments or other similar (e.g., Internal Revenue Service)	Advanced knowledge of the possibilities of carrying out procedures and procedures with government agencies (for example, IRS, apply for government funding, enrollment in courses, etc.)
Baseline (n)	2	30	0	0	0

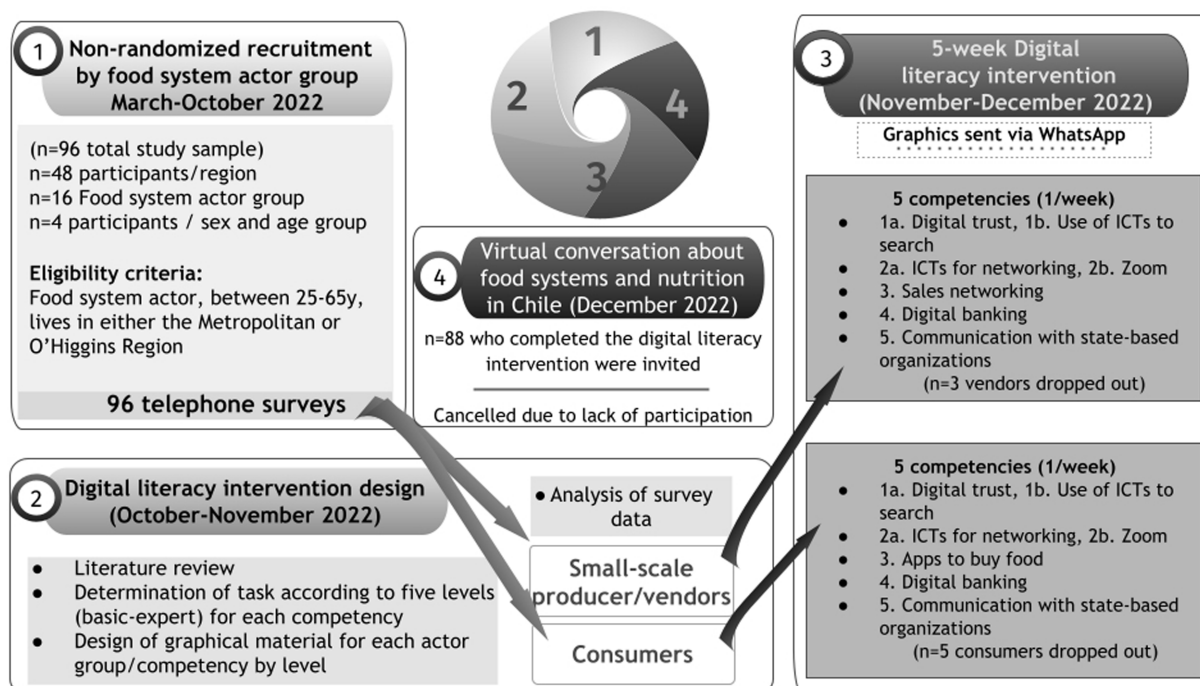


FIGURE 1
Pilot study timeline and procedures.

more intensive action” (Food Systems Dialogues, 2019). The purposes of the FSD were to convene the food system actors to engage in an interactive dialogue, including about the digital literacy intervention for improving Chilean food systems and nutrition, to close out the project, and to assess inherent digital literacy levels through one’s capacity to use Zoom.

Intervention process indicators

Multiple process indicators were defined to assess the implementation of the intervention and if it was successful. Reach was defined as those with a valid cell phone number as well as with WhatsApp during the first week of the intervention based on the premise that if a participant could be sent the digital intervention materials during the first week, they would be able to receive intervention materials during the four subsequent intervention weeks; and the average reach was determined based on these two indicators. Dose delivered was defined as the percentage of participants that received all of the digital intervention materials as indicated by the WhatsApp double check mark system that indicates that a user has received the message and did not include participants lost to follow up. Dose received was defined as two different aspects of participant engagement: receptivity to materials and satisfaction. Dose received related to the receptivity of materials was defined as the percentage of participants that viewed all of the digital intervention materials according to the WhatsApp blue check mark system that indicates when a user has viewed the message. Dose received related to satisfaction was defined as any time a participant responded positively to the intervention materials, such as through messages sent in response or emoticons; that also reflected the absence of participant discontent or desire to abandon the study (Ishaq Bhatti et al., 2014; Georgsson and Staggers, 2016). The average dose received was based on both indicators of dose received. To determine an overall implementation score we utilized the multiplicative approach based on the following equation: average reach multiplied by dose delivered multiplied by average dose received multiplied by average fidelity (Steckler and Linnan, 2002). Given that the intervention was designed and sent on schedule as planned we assumed a fidelity of 100%.

Statistical analysis

Descriptive statistics were used to illustrate both the baseline characteristics and the outcome variables related to the digital literacy intervention of all participants initially enrolled in the study stratified by actor group (small-scale farmer, vendor, and consumer) and region (Metropolitan and O’Higgins). Many of the baseline characteristics entailed categorical variables for which proportions were calculated. While means were calculated for the continuous variables. For the questions with a categorical response that were asked in the context of three different time periods (i.e., before the social crisis, during the social crisis, and during the COVID-19 pandemic), as well as the distance one reported from a farmers market, the chi-squared test was used to determine if the distribution of these variables was statistically significantly different across each actor-region group. Chi-squared tests were also used to determine if statistically significant differences existed between baseline characteristics related to digital literacy and

by actor group. For example, whether having internet at home or a preferred means of communication was statistically significantly different between small-scale farmers, vendors, and consumers. For each chi-squared test that was performed, statistical significance was set at $p < 0.05$. All statistical analyses were conducted using STATA 17.0/SE (StataCorp, 2021).

Ethical considerations

The study was approved by the ethics committee of the University of Chile. Verbal informed consent was obtained from all participants after the study protocol had been explained to them over the telephone in Spanish.

Results

Sociodemographic characteristics and ICT use

Nearly a third (28%) of participants expressed that they or their household had experienced some form of food insecurity between 2021 and 2022; 96% of which was attributed to the COVID-19 pandemic (Table 2). Almost all participants reported having received some form of State support due to the COVID-19 pandemic, mainly emergency family income payments for income relief during COVID-19 to economically vulnerable households. Across regions, vendors reported greater overweight or obesity, type 2 diabetes, and COVID-19 compared to farmers and consumers (Table 2). Most consumers had completed higher education and reported that someone in the household was teleworking due to the COVID-19 pandemic. Most of both vendors and consumers reported that someone teleworking in the household due to the COVID-19 pandemic affected mealtimes. Farmers and vendors in both regions reported either sometimes or always having cell signal problems while over half of consumers in both regions reported never having cell signal problems. Having both internet and a computer at home was >60% across all actor groups, except rural farmers in which only 38% had internet at home and 50% reported having a computer at home. Most urban consumers reported knowing how to use a computer (88%), compared to 69% of rural consumers, 50% of urban vendors, approximately 40% of all farmers, and only 38% of rural vendors. More farmers in urban areas (37%) preferred television as a form of mass communication compared to farmers in rural areas who preferred internet web pages (44%). Television was the preferred form of mass media across vendors. Consumers were split in their preferred form of communication between television and internet web pages. In both regions, many participants used their cell phones to make and receive calls, use the internet, chat (e.g., WhatsApp), and social media. Almost all participants reported that they knew how to read and send a WhatsApp message (99%) and how to use email (86%). Urban consumers (66%) and rural farmers (55%) were the only groups in which over half reported having a dedicated work email. Compared to consumers and farmers, fewer vendors reported using online banking, and only half of rural vendors reported using online Bill Pay. However, 50% of rural vendors reported that they started an online business during the COVID-19 pandemic for more income, more

TABLE 2 Socio-demographic characteristics and information and communications technology (ICT) use by region Urban RM (Metropolitan Region) or Rural OH (O'Higgins Region) and actor group (Ag: small-scale producer, Ven: vendor, and Con: consumer).

	RM-Ag (<i>n</i> = 16)	OH-Ag (<i>n</i> = 16)	RM-Ven (<i>n</i> = 16)	OH-Ven (<i>n</i> = 16)	RM-Con (<i>n</i> = 16)	OH-Con (<i>n</i> = 16)	Total (<i>n</i> = 96)	<i>p</i> value (χ^2)
Age (y)	44	47	44	40	43	43	44	
Household members (<i>n</i>)	4	3	4	4	3	4	4	
During the past 12 months, did you or someone else in HH worry about not having enough food to eat due to lack of money or other resources? (%)	25	31	19	38	19	38	28	
Was HH food insecurity due to COVID-19? (%)	75	100	100	100	100	100	96	
Do you have Overweight/obesity? (%)	19	12	25	50	56	31	32	0.049*
Do you have CVD? (%)	0	0	0	6	6	6	3	NS
Do you have Hypertension? (%)	19	19	6	12	6	12	12	NS
Do you have T2D? (%)	0	19	25	19	0	6	11	NS
Do you have any cancer? (%)	0	6	6	0	0	6	3	NS
Do you have COVID-19? (%)	12	19	31	44	19	12	23	NS
HH member with any chronic condition above (%)	62	50	69	62	62	31	56	NS
Highest education completed (%)								NS
Primary	19	19	31	19	0	0	15	
Secondary	31	50	31	50	19	38	36	
Technical	25	12	12	12	12	12	15	
Higher education	25	19	25	19	69	50	34	
Anyone in HH teleworking due to COVID-19? (%)	31	25	40	25	81	62	44	0.004**
Did the teleworking affect meal times? (%)	40	25	67	75	62	90	64	NS
Anyone in HH without work due to COVID-19? (%)	19	19	31	38	31	44	30	NS
Did the above affect your ability to buy food? (%)	67	67	40	67	40	57	55	NS
Received state support due to COVID-19? (%)	94	88	100	100	81	100	94	NS
Do you use your cell phone? (%)	100	94	100	100	100	100	99	NS
How much do you spend a month on your cell phone? (%)								NS
Monthly cell phone costs (USD\$1.30–6.30)	0	0	0	6	0	6	2	
Monthly cell phone costs (USD\$6.30–12.30)	25	31	12	38	31	44	30	
Monthly cell phone costs (>USD\$12.30)	75	62	75	50	69	50	64	
Do not know	0	6	12	6	0	0	4	
Normally how is your cell phone signal at home? (%)								NS
Never have cell signal problems	25	19	44	44	56	62	42	
Sometimes cell signal problems	44	44	44	25	38	25	36	
Always cell signal problems	31	38	12	31	6	12	22	
Internet at home (%)	62	38	94	75	94	94	76	<0.000*
Computer at home (%)	69	50	81	75	100	81	76	0.035*
Use a computer (%)	43	40	25	38	88	69	51	0.004**
What is your preferred means of communication? (%)								NS
Preferred communication-TV	38	19	50	38	31	38	35	
Preferred communication-Radio	12	6	0	12	19	12	10	
Preferred communication-Newspaper	0	0	6	0	6	0	2	

(Continued)

TABLE 2 (Continued)

	RM-Ag (n = 16)	OH-Ag (n = 16)	RM-Ven (n = 16)	OH-Ven (n = 16)	RM-Con (n = 16)	OH-Con (n = 16)	Total (n = 96)	p value (χ^2)
Preferred communication-Internet web pages	31	44	25	25	31	44	33	
Preferred Communication-Social Media	19	31	19	25	12	6	19	
Know how to open a text (SMS) message (%)	88	81	62	81	100	100	85	0.026*
What do you do when you receive a text (no WhatsApp) from someone known? (%)								NS
When receiving a text message from someone known-almost never read it	0	8	0	8	0	0	2	
When receiving a text message from someone known-sometimes read it	0	15	0	8	0	0	4	
When receiving a text message from someone known-almost always read it	14	0	20	15	6	25	13	
When receiving a text message from someone known-always read it	86	77	80	69	94	75	80	
Know how to read a WhatsApp message (%)	100	94	100	100	100	100	99	NS
Know how to send a WhatsApp message (%)	100	94	100	100	100	100	99	NS
Use email (%)	81	73	81	94	94	94	86	NS
Use a dedicated work email (%)	38	55	23	47	67	47	46	NS
Use online banking (personal and/or work) (%)	69	56	56	56	100	81	70	0.033*
Do online Bill Pay (%)	62	56	56	50	100	81	68	0.020*
During COVID-19, used social media to receive nutrition information and/or healthy eating tips (%)	50	38	38	31	75	62	49	NS
During COVID-19, have you started an online business for more income? (%)	44	38	38	50	31	19	36	NS
During COVID-19, have you started businesses like selling fruit/veg or foods from home to adapt your actual business? (%)	50	31	38	50	0	7	29	0.005**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; z NS, not significant.

than farmers and consumers, while 50% of urban farmers reported adapting their actual business during the COVID-19 pandemic, such as selling more fruits and vegetables from home, to complement their income. Also, during the COVID-19 pandemic, two-thirds of consumers in both regions accessed social media to receive nutrition information and/or healthy eating tips which was more than farmers and vendors, respectively.

Trends in the food environment across food system actors and crises

Most of the study participants reported being the primary food shopper for the household, except for rural vendors (Table 3), which, across groups, was statistically significantly different by sex ($p = 0.045$, data not shown). Before the Chilean social crisis in October 2019, across food system actor groups and regions, 79% of participants reported buying food for their household from supermarkets, this ranged from 94% of rural farmers to 62% of urban vendors. During the Chilean social crisis, however, 66% of participants reported buying food for their household from supermarkets, and the percentage of participants buying food from neighborhood stores increased from

3% before the Chilean social crisis to 11%. With the onset of the COVID-19 pandemic, the number of participants buying food from supermarkets declined even further to 57%, while delivery increased to 17% compared to only 2% before the Chilean social crisis, and was highest amongst urban farmers and vendors (p for trend = 0.011). While nearly all participants reported having access to a farmers market in their community, the distance to the farmers market varied widely and was statistically significantly different across actor-region groups ($p < 0.000$). Only 36% of participants had a farmers market within less than 1 kilometer from home, especially urban vendors and consumers. Approximately 40% had a farmers market more than 3 kilometers away, including 9 participants who reported a farmers market within 18–25 kilometers from home. Before the October 2019 social crisis, 60% of all participants reported going to the farmers market on a weekly basis. During both the social crisis and COVID-19 pandemic weekly attendance declined to 42 and 32%, respectively, and 60% of urban farmers reported never going to a farmers market during these time periods. Except for urban vendors, over a third of all participants reported that they or someone in their household has used social media to obtain food for the household, including 62% of urban consumers. Of these participants, 81% reported using WhatsApp to obtain food. Most urban consumers reported that their

TABLE 3 Food environment characteristics by region Urban RM (Metropolitan Region) or Rural OH (O'Higgins Region) and actor group (Ag: small-scale producer, Ven: vendor, and Con: consumer).

	RM-Ag (n = 16)	OH-Ag (n = 16)	RM-Ven (n = 16)	OH-Ven (n = 16)	RM-Con (n = 16)	OH-Con (n = 16)	Total (n = 96)	p value (χ^2)
How many people have been eating regularly in your HH over the past 30 days? (n)	4	3	4	4	3	3	4	
Does the majority of food shopping for the HH (%)	69	69	88	56	62	81	71	
Before the social crisis, main place to buy food (%)								NS
Delivery	6	0	0	0	0	6	2	
Supermarkets	75	94	62	81	88	75	79	
Corner store/ minimarket	0	0	6	0	0	0	1	
Neighborhood store	6	0	6	0	0	6	3	
Produce shop	0	0	6	0	0	0	1	
Farmers market	6	6	19	19	12	12	12	
Other (Wholesale)	6	0	0	0	0	0	1	
During the social crisis, main place to buy food (%)								NS
Delivery	19	0	0	0	6	6	5	
Supermarkets	62	88	56	56	62	69	66	
Corner store/ minimarket	6	0	6	0	6	6	4	
Neighborhood store	6	12	6	25	12	6	11	
Produce shop	0	0	6	6	0	0	2	
Farmers market	0	0	25	12	12	12	10	
Other (Wholesale)	6	0	0	0	0	0	1	
During the COVID-19 pandemic, main place to buy food (%)								NS
Delivery	25	12	25	6	12	19	17	
Supermarkets	56	62	44	44	75	62	57	
Corner store/ minimarket	0	6	0	0	0	0	1	
Neighborhood store	6	6	0	19	12	6	8	
Produce shop	0	0	6	6	0	0	2	
Farmers market	6	12	25	25	0	12	14	
Other (Wholesale)	6	0	0	0	0	0	1	
p for trend across the three time periods								0.011*
Do you have access to a farmers market in your community? (%)	94	94	100	100	100	94	97	NS
Before the social crisis, how often went to farmers market (%)								0.001**
Never	40	7	6	0	19	13	14	
A few times a year	7	33	6	0	6	7	10	
Once a month	0	20	0	12	19	0	9	
Every 2 weeks	0	0	6	0	19	20	8	
Every week	53	40	81	88	38	60	60	
During the social crisis, how often went to farmers market (%)								<0.000***
Never	60	13	12	0	38	33	26	
A few times a year	0	27	0	0	6	7	6	
Once a month	7	27	0	19	31	7	15	

(Continued)

TABLE 3 (Continued)

	RM-Ag (n = 16)	OH-Ag (n = 16)	RM-Ven (n = 16)	OH-Ven (n = 16)	RM-Con (n = 16)	OH-Con (n = 16)	Total (n = 96)	p value (χ^2)
Every 2 weeks	13	7	6	0	12	27	11	
Every week	20	27	81	81	12	27	42	
During the COVID-19 pandemic, how often went to farmers market (%)								0.001**
Never	60	33	25	12	44	33	34	
A few times a year	7	27	0	0	38	13	14	
Once a month	7	27	12	12	0	7	11	
Every 2 weeks	13	7	12	0	6	13	9	
Every week	13	7	50	75	12	33	32	
p for trend across the three time periods								0.007**
Distance to farmers market (%)								<0.000***
<1 KM	0	13	69	38	69	27	37	
1 KM	7	0	12	12	19	33	14	
>1–2 KM	20	0	6	6	12	20	11	
3–5 KM	27	20	0	6	0	20	12	
6–8 KM	13	7	0	12	0	0	5	
9–13 KM	20	33	6	12	0	0	12	
18–25 KM	13	27	6	12	0	0	10	
Since the COVID-19 pandemic, have you or anyone in HH used social media to obtain food for the HH? (%)	31	38	19	44	62	38	39	NS
Specifically via Whatsapp	60	100	67	86	90	67	81	NS
Specifically via Facebook	60	50	67	0	10	33	30	NS
Specifically via Instagram	60	17	33	14	60	50	41	NS
Specifically via other platforms	0	17	33	14	60	50	32	NS
Are you the main cook in your HH? (%)	44	56	62	38	50	56	51	
Since the COVID-19 pandemic, has delivery of prepared food increased in your HH? (%)	25	19	25	25	88	25	34	<0.000***
Before the social crisis, did the people in your HH eat together at the same table? (%)	69	100	75	62	73	69	74	NS
During the social crisis, did the people in your HH eat together at the same table? (%)	69	87	69	69	87	88	78	NS
Since the COVID-19 pandemic, did the people in your HH eat together at the same table? (%)	81	93	81	88	100	81	87	NS
p for trend across the three time periods								NS

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; NS, not significant.

use of delivery to obtain prepared food increased in their household during the COVID-19 pandemic which was not the case for the other groups. Before the social crisis in October 2019, among all participants, 75% reported eating together at the same table in the household which increased to 87% during the COVID-19 pandemic.

Farmer characteristics related to crisis

Farmers in both study regions experienced changes related to their agricultural production during each of the three crises in Chile:

the social crisis, the COVID-19 pandemic, and climate change (Table 4). While the number of people who worked on the farm did not change over the study period, approximately half of all farmers reported that it has been harder to find workers either due to the COVID-19 pandemic or due to climate change. Most of the farmers in both regions use drip irrigation and reported having to make changes in their agricultural production due to the drought. Approximately half of the farmers reported using fertilizers, pesticides, or herbicides. Independent of input type, half of the farmers also reported that how much they spend on inputs has changed with climate change and during the COVID-19 pandemic. Two-thirds of

TABLE 4 Farmer characteristics by region Urban RM (Metropolitan Region) or Rural OH (O'Higgins Region).

	RM (<i>n</i> = 16)	OH (<i>n</i> = 16)	Total (<i>n</i> = 32)
Before the COVID-19 pandemic, how many people (inc. family) worked on the farm (<i>n</i>)	5	4	5
During the social crisis, how many people (inc. family) worked on the farm (<i>n</i>)	5	4	5
Since the COVID-19 pandemic, how many people (inc. family) worked on the farm (<i>n</i>)	5	4	4
During the social crisis, has it been harder to find workers? (%)	25	50	38
Since the COVID-19 pandemic, has it been harder to find workers? (%)	38	62	50
Due to climate change, has it been harder to find workers? (%)	31	62	47
What type of watering system do you use? (%)			
None	6	6	6
Irrigation by laying	6	6	6
Drip irrigation	69	44	56
Furrow irrigation	6	12	9
Other	12	31	22
Due to the drought, have you had to make changes in your agricultural production? (%)	62	69	66
What type of inputs do you use: None (%)	6	6	6
What type of inputs do you use: Fertilizers (%)	62	44	53
What type of inputs do you use: Pesticides (%)	50	44	47
What type of inputs do you use: Herbicides (%)	44	44	44
What type of inputs do you use: Other (%)	50	56	53
Has how much you spend on inputs changed with the social crisis? (%)	44	0	23
Has how much you spend on inputs changed with the COVID-19 pandemic? (%)	69	36	53
Has how much you spend on inputs changed with climate change? (%)	50	57	53
Do you use machines for production? (%)	75	75	75
Do you own these machines? (%)	58	50	54
Due to climate change, are you motivated to make changes in machine use or other changes to continue producing? (%)	33	42	38
Due to the COVID-19 pandemic, are you motivated to make changes in machine use or other changes to continue producing? (%)	17	0	8
Due to the social crisis, has the price of gas increased? (%)	8	0	4
Due to the COVID-19 pandemic, has the price of gas increased? (%)	50	67	58
Due to climate change, has the price of gas increased? (%)	67	83	75
Due to the COVID-19 pandemic, have you had to sell your products via digital platforms (%), if so which platform	50	50	50
Facebook (<i>n</i>)	0	1	1
Instagram (<i>n</i>)	0	1	1
Instagram, WhatsApp (<i>n</i>)	0	1	1
WhatsApp (<i>n</i>)	7	1	8
WhatsApp, Facebook (<i>n</i>)	1	3	4
WhatsApp, Web page (<i>n</i>)	0	1	1
Due to climate change, do you know anyone that has decided to abandon agriculture? (%)	56	38	47
Due to the residential building pressure to urbanize, do you know anyone that has decided to abandon agriculture? (%)	69	19	44
Before the COVID-19 pandemic, did you maintain contact with extension or technical assistance? (%)	75	81	78
What method did you use to maintain contact with them? (%)			
In person	50	100	76
Phone call	25	0	12

(Continued)

TABLE 4 (Continued)

	RM (<i>n</i> = 16)	OH (<i>n</i> = 16)	Total (<i>n</i> = 32)
WhatsApp	25	0	12
During the social crisis, did you maintain contact with extension or technical assistance? (%)	62	81	72
What method did you use to maintain contact with them? (%)			
In person	40	92	70
Phone call	30	0	13
WhatsApp	30	8	17
During the COVID-19 pandemic, did you maintain contact with extension or technical assistance? (%)	69	88	78
What method did you use to maintain contact with them? (%)			
In person	9	29	20
Phone call	18	43	32
Whatsapp	64	29	44
Other	9	0	4
Do you use a computer or cell phone for work related to your agricultural production? (%)	62	69	66
If so, what specific features do you use (%)			
Whatsapp	56	69	62
Facebook	19	31	25
Email	6	6	6
Text message	6	0	3
Phone call	19	25	22
Other	6	6	6
Which means of information to you prefer for technical assistance and/or workshops (%)			
Visits to land by extensionist	19	56	38
Visit days	31	19	25
Demonstrative farms	50	19	34
Forums or roundtables	0	6	3

farmers use mechanization for production, but only 38% reported that they are motivated to make changes in mechanization or other changes to continue producing agriculture. Two-thirds of farmers also reported that they believe the price of gas has increased due to climate change, while 58% believe that the price of gas also changed due to the COVID-19 pandemic. Half of the farmers reported that during the COVID-19 pandemic, they had to sell their products via digital platforms, primarily through WhatsApp. Approximately half of the farmers in this study also reported that due to climate change, they knew of someone who had decided to abandon agriculture while 44% of farmers reported that they knew someone who had decided to abandon agriculture due to the residential building pressure related to urbanization. Prior to the social crisis up through the COVID-19 pandemic, most farmers maintained contact for extension or technical assistance, but what was previously in-person contact changed to phone calls (32%) or WhatsApp (44%) during the COVID-19 pandemic. Specifically, more rural farmers preferred phone calls to maintain contact for extension or technical assistance during the COVID-19 pandemic compared to urban farmers (43% vs. 18%), while urban farmers preferred WhatsApp (64% vs. 29%). The means of information that a farmer preferred for technical assistance and/or workshops also varied by region. Over half of rural farmers preferred

in-person visits by an extensionist, while half of urban farmers preferred to visit demonstrative farms.

Digital literacy intervention and food systems dialogue

This pilot study from which we are presenting results was done to validate the digital literacy intervention. The baseline digital literacy level statistically significantly differed between farmers, vendors, and consumers across some variables, including having internet at home, using a computer, and online Bill Pay (Table 2), revealing that farmers and vendors have similar digital literacy levels compared to that of consumers. Thus, although the 5 digital literacy intervention competencies were similar across food system actor groups and regions, the expectations for each level (basic through expert) were different for consumers. For example, for the key competency digital trust level 1 for small-scale farmers and vendors was “Fear and insecurity of technology,” while for consumers it was “Apply data protection measures such as double encryption and secure locks (Table 1).” In addition, the third key competency of sales networking was tailored to small-scale farmers and vendors to consider their

TABLE 5 Intervention process indicators by food system actor group and region Urban RM (Metropolitan Region) or Rural OH (O'Higgins Region).

	Farmer (RM) (n = 16)	Farmer (OH) (n = 16)	Vendor (RM) (n = 16)	Vendor (OH) (n = 16)	Consumer (RM) (n = 16)	Consumer (OH) (n = 16)	Total (n = 96)
Reach: % with a valid number during 1st intervention week	100	100	100	100	100	100	100
Reach: % with WhatsApp during 1st intervention week	100	94	100	88	94	94	95
Average reach %	100	97	100	94	97	97	98
Dose delivered: % received all digital intervention	100	100	100	81	94	75	92
Dose received (receptive to materials): % viewed all digital intervention ¹	94	88	88	75	94	69	84
Dose received (satisfaction): % expressed satisfaction with digital intervention in any week	81	56	25	37	69	44	52
Average dose received %	88	72	57	56	82	57	68
Intervention implementation score (%) (Average reach*dose delivered*average dose received*fidelity ²)	88	70	57	43	75	41	61
% Participated in food systems dialogue (FSD)	0	0	6	0	0	0	6
% Expressed satisfaction with FSD	0	0	6	0	0	0	6

¹Based on WhatsApp blue check mark system.²Assumes an intervention fidelity of 100%.

business needs while for consumers the third key competency was “Continuous and extensive use of APPs to buy food (e.g., UberEats).” During the first week of the digital intervention, all 96 survey participants were included and sent the first intervention material to a valid number and only a few participants did not have WhatsApp at the time (Table 5). All farmers and urban vendors received all 5 weeks of the digital intervention while some participants in the other groups declined to participate at some point. Of those who received all of the digital intervention, most participants viewed all the digital intervention materials, except for rural consumers according to the blue check marks feature of WhatsApp. Most urban farmers and consumers also expressed their satisfaction with the digital intervention at any week during the intervention (e.g., responding “Many thanks” or “Thanks, I’ll share it with the community”). The overall implementation score was highest amongst urban farmers (88%) and consumers (75%), and lowest amongst rural vendors (43%) and consumers (41%) (Table 5). All 88 participants who completed the dialogue literacy intervention were invited to the food systems dialogue over Zoom to close out the project. Ten people expressed interest via WhatsApp message in attending the event. After waiting 20 minutes, only one person, a rural farmer, showed up and thus, the food systems dialogue was canceled for lack of a suitable quorum (three people minimum) for the activity. The rural farmer that showed up expressed interest in the study and such an event because “We want everything to be more organic, better for health and society. So I’m interested if you all do another dialogue in the future.” After the event closed, five people expressed barriers to attending the event after its conclusion which included being busy with farm work and not being proficient in Zoom, forgetting about the event, and family caregiving.

Discussion

A digital literacy intervention was moderately implemented amongst key food system actors (small-scale farmers, vendors, and consumers) in the Metropolitan and O’Higgins regions of Chile. Thus, when considering all the intervention process indicators, implementation was highest amongst ($\geq 70\%$) farmers and urban consumers, but lower amongst the other groups, with an average of 61%. The pilot implementation took advantage of tailoring a digital literacy intervention to distinct actors in the food system based on their baseline digital literacy level, and that nearly all participants knew how to read and send WhatsApp messages. During the intervention study, we carried out most of the activities envisioned within the operational plan. The objectives, subject population, and 5-week intervention timeline were not significantly altered during the pilot study implementation. However, the methodological strategy of a food systems dialogue to assess the acceptability of the digital literacy intervention had to be adjusted, and ultimately canceled, because the attendance of only one participant prevented its successful implementation.

As indicated in the Introduction, our secondary purpose was to identify how the fragility of food systems in Chile had manifested itself during concomitant crises (social, COVID-19, climate change) and elucidate trends in the usage of information and communication technologies (ICTs) to produce, sell, and consume food over this period. In both regions, half of the farmers declared knowing someone who abandoned agriculture due to climate change. The pilot study also revealed statistically significant changes in the main source of food for the household comparing

the time periods before the social crisis, during the 2019 social crisis, and during the COVID-19 pandemic, and indicated that the COVID-19 pandemic stimulated additional business models and sources of income. During the COVID-19 pandemic, a third of all participants started an online business for more income, while farmers and vendors made adaptations to their actual business to sell more fresh fruit and vegetable products.

Some of the main contributors to the success of the pilot study was the focus on conducting the study entirely virtually and tailoring the digital literacy intervention to each food systems actor group. Analyses of telephone surveys involving small-scale farmers, farmers market vendors, and consumers indicated that small-scale farmers and vendors have a different baseline digital literacy level and, as expected, have different needs for digital tools from those of consumers. For example, more small-scale farmers and vendors reported starting an online business as well as adapting their actual business to sell foodstuffs from home during the COVID-19 pandemic for more income. Amongst all participants, there was a notable trend in the decline of supermarkets as the main place to buy food for the household during the Chilean social crisis and the COVID-19 pandemic, and a parallel increase in delivery as the main means to obtain food for the household. To the best of our knowledge, this is the first digital literacy intervention to be designed and implemented across different food system actors, in any setting. With the COVID-19 pandemic, there is a greater awareness of digital literacy as a limiting factor in telemedicine utilization in the United States (Bejarano, 2022), but scientific studies of digital literacy are severely lacking in other areas, such as food access.

The incorporation of ICTs into both professional and personal life shows no signs of abatement, but little is known about how digital literacy is an essential component of ICT use. One area where ICTs have been explicitly studied in relation to digital literacy and that has increased dramatically since 2012 is with regard to digital health interventions (Benny et al., 2021). In their review of digital health interventions between 2001 and 2020, of which only 7 of 131 eligible studies included digital literacy, Benny et al. assert that there is no clear explanation as to why studies about health literacy have dramatically exceeded those about digital literacy. Further corroborating the findings of the review by Benny et al., reviews since 2021 on digital literacy have also focused on health outcomes (Campanozzi et al., 2023), and specific segments of the population, such as older adults (Oh et al., 2021) and students (Gutiérrez-Ángel et al., 2022; Nogueira et al., 2022). While the COVID-19 pandemic elucidated the importance of digital literacy for students inadvertently forced into online learning and an increased reliance on telemedicine by the elderly, there is still a paucity of digital literacy research, let alone interventions, as it relates to other areas essential for human resilience.

In our study, we obtained a group of food system actors representative of other small-scale producers, vendors, and consumers when compared with similar food system actors across Latin America, in terms of the increase in, and utilization of, home delivery services through digital platforms, especially of fresh foods, during the COVID-19 pandemic (Boza, 2021). For scaling up the intervention more broadly to the Chilean population, it will be important to assess digital literacy levels and interest through shorter more flexible instances. Study participants demonstrated a high level of receptivity to the digital literacy intervention in terms of viewing all the materials

and only eight participants did not complete the full 5-week intervention. Rural consumers were the only group in which less than two-thirds of participants viewed all of the digital intervention materials.

Strengths and limitations

Throughout the course of the digital intervention, participants, especially urban farmers and consumers, expressed satisfaction and perceived benefit that is consistent with other personalized mobile health interventions (Alessa et al., 2018; Cao et al., 2022). Despite the moderate success of the pilot study, we encountered several barriers related to the successful implementation of the food systems dialogue and thus, the assessment of digital literacy in general. The low attendance is consistent with emerging literature on the challenges in qualitative research using online video conferencing methods, especially with underserved populations and in the absence of childcare, even when advanced training (e.g., how to use Zoom) is offered (Lathen and Laestadius, 2021; Tran et al., 2021). These findings are important for considering the replication of a similar digital literacy intervention in other regions of the country. Organizers of such interventions or synchronous virtual events will need to consider alternative ways to assess digital literacy as well as co-creating the event with targeted participants to select a more feasible time and foster greater accountability to show up. Another important barrier that the study faced because the food systems dialogue could not be completed was the lack of an alternative method within the study protocol to assess digital literacy as well as other indicators of intervention satisfaction/usability post-intervention. One study, however, suggests that the blue check marks in WhatsApp when one views a message are related to the fact that some participants prefer to listen rather than verbally express satisfaction through other means (Yeshua-Katz, 2021). Future implementation of digital literacy interventions will also require infrastructure resources to improve cellular signal coverage, especially for small-scale producers that, even though they may live in urban and rural areas, are more likely to be working in more remote areas.

To the best of our knowledge, this is the first digital literacy intervention specifically tailored to and implemented amongst food systems actors. The fact that nearly all participants knew how to read and send a WhatsApp message reflects the increasing prevalence of WhatsApp in global health services research (Manji et al., 2021), participatory research in other Latin American settings (Börner et al., 2023), and within food systems (Samoggia et al., 2021). Participants were able to express a form of satisfaction with the digital literacy intervention because they were already proficient with WhatsApp. We believe that the positive comments observed are likely because the participants truly liked the intervention material even though we did not capture more specific information related to the perception of the intervention content. However, it is inherently challenging to implement a digital literacy intervention through digital means because it is possible that a lack of digital literacy, and/or cellular signal, may still limit user participation and satisfaction during the intervention. Future studies might also consider giving part of a digital literacy intervention in person, with virtual follow-up.

Policy implications

This study has implications for public policy and research within Chile as well as the Latin American region, if not globally. Given the growing incidence of extreme weather events due to climate change, such as massive flooding in the O'Higgins region that instantaneously affected both food production and consumption (Gálvez and Canales, 2023), there is an even greater imperative for multiple ministries (e.g., agriculture, social and family development, health, education, women and gender equity) to incorporate digital literacy programming into their materials. For example, the Uruguayan government through its Ministry of Education and Culture has a National Plan for Digital Literacy (PNAD, for its acronym in Spanish) that consists of free guided workshops for the population on different digital literacy objectives (Ministerio de Educación y Cultura and Centro MEC, 2010). The government of Nigeria, a middle-income country, through its National Digital Economy Policy and Strategy, has set a goal of achieving 95% digital literacy by 2030 with a related agenda for how to do so through its National Digital Literacy Framework (NITDA, 2019, 2023). Chile and other countries globally might consider adapting similar public policy efforts that aim to increase digital literacy levels nationwide in an equitable manner, rather than inadvertently exacerbating an already existing digital divide.

Conclusion

Based on the study results we conclude that different crises in Chile, from a social crisis in October 2019 to ongoing climate change to the COVID-19 pandemic, have impacted how the Chilean population in both urban and rural regions navigate their food environment for their household as well as small-scale agricultural production in these areas. This taken together has elucidated a greater dependence on ICTs amongst small-scale farmers, vendors, and consumers in Chile to buy and/or sell food. Amongst these key food systems actors, we determined that it is feasible to implement a digital literacy intervention for key food system actors in urban and rural settings in Chile. Therefore, we conclude that the digital literacy intervention was successfully implemented across food system actor groups in the urban Metropolitan region as well as rural small-scale farmers. The results also suggest that basic literacy in WhatsApp facilitated the implementation of this pilot study. It is important to adapt a digital literacy intervention to the distinct realities of small-scale farmers and farmers market vendors, especially in rural areas, compared to consumers and better understand the context-specific barriers to implementation in rural areas to improve the design of subsequent digital literacy interventions. In future analyses, it will be important to include measures related to implementation outcomes beyond those used in this study to assess the impact of a digital literacy intervention more precisely on improvements in digital literacy. The experience of this pilot study in two different regions in Chile has implications for policy and research both in Chile and for the Latin American region. Future projects and studies will contribute to the evidence base about the feasibility and impact of similar digital literacy interventions, an area of increasing importance due to the

rising prevalence of the digital food environment worldwide. In conclusion, greater digital literacy amongst food systems actors will help strengthen local food systems for concomitant crises and climate change in an increasingly digitalized world.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethics Committee on Human Subjects Research of the Faculty of Medicine of the University of Chile. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because this study was conducted entirely through virtual means. Therefore, permission was granted to obtain only verbal informed consent.

Author contributions

RK, SB, and PA-S were involved with conducting the study that is the base of this manuscript. RK led the analyses and drafted the manuscript. SB provided the critical contributions to the text, including suggestions for additional analyses, and interpretation of the results. PA-S led the digital literacy intervention and contributed primarily to this part of the methods section of text. All authors reviewed and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Impacts of the COVID-19 pandemic on food systems in Manitoba, Canada and ways forward for resilience: a scoping review

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Various studies over the past 3 years have synthesized trends and impacts of the COVID-19 pandemic on Canada's national food system. However, less research has characterized the effects of COVID-19 within regional and provincial food system contexts. This article presents results from a scoping review of peer-reviewed and grey literature published from March 2020 until end of March 2023 examining the impacts of the COVID-19 pandemic on food systems in the province of Manitoba, Canada. Findings are presented according to the categories of food security funding, policy, and programming; individual and household food security; and food systems. In each area we synthesize key findings and discuss their significance in relation to existing food systems scholarship and national trends. Using review results, we propose priority areas for research and practice to support equitable and resilient food systems in Manitoba, including: (1) undertaking evaluation of food system policies, programs, and funding implemented during the pandemic (2) enhancing food security monitoring for vulnerable populations (3) further exploring community experiences and responses to food security, and (4) examining opportunities for local food systems development.

KEYWORDS

pandemic (COVID19), Manitoba, food systems, resilience, food policy

1 Introduction

The outbreak of the COVID-19 pandemic in early 2020 presented significant challenges to Canada's food systems, from disrupted supply chains to business closures and heightened demand for emergency food aid (Hobbs, 2020; Holland, 2020). The situation of individuals and communities that were already precarious within food systems, such as temporary foreign labourers and those already experiencing food insecurity, worsened (Arrell Food Institute and Canadian Agri-food Policy Institute, 2021; Polysky and Garriguet, 2022). A range of funding and policy measures were rolled out, with the pandemic prompting debate about how Canada's food system should be rebuilt and renewed to enhance resilience to similar disruptions in the future (James et al., 2021; Regnier-Davies et al., 2022).

While various studies over the past several years have synthesized trends and impacts of the COVID-19 pandemic on Canada's national food system, less research has been devoted to characterizing the effects of COVID-19 within regional and provincial food system contexts. However, doing so is crucial to a fuller understanding of the place-based impacts of the

pandemic and informing future efforts for food system resilience. This scoping review responds to this gap by examining how the pandemic affected food systems in the province of Manitoba, Canada. Specifically, this review synthesizes peer reviewed and grey literature to provide a picture of pandemic impacts and responses in the province's food systems. Questions guiding this review include: How have food systems in rural, urban, and Northern/remote communities in Manitoba changed due to the pandemic? What were the impacts for food access among households and vulnerable populations? What policy, programming, and funding responses took place?

By food systems, we are referring to all the steps involved in feeding a population, including the stages through which foods pass and are transformed as they move from field, water, to plate, and beyond (Tansey and Worsley, 1995). Food systems are thus necessarily complex, involving interactions among economic, social, political, and environmental components (Tansey and Worsley, 1995). Manitoba's food systems are characterized by high levels of industrial agriculture development, alongside a large Indigenous population, many Northern and remote communities, and a strong and growing network of local food policy actors and community-based food security initiatives. While these features make Manitoba's food systems complex, these diverse characteristics also make the findings from this scoping review relevant to other jurisdictions across Canada and North America that share similar structural attributes and policy environments.

Although we are arguably in a post-pandemic period, we believe this scoping review remains timely in a context of pandemic recovery and ongoing pressures, such as food price inflation, supply chain disruption, climate change, extreme weather events, and global geopolitical instabilities, that continue to affect food systems in Manitoba and Canada. We discuss the significance of our findings in Manitoba in the context of existing food systems scholarship and national trends and conclude by proposing priority areas for research and practice to support equitable and resilient food systems in Manitoba.

2 Methods

A scoping review research method was used to synthesize research about the effects of the COVID-19 pandemic on food systems in Manitoba covering the period from March 2020 to the end of March 2023. A scoping review was an appropriate method for our study which sought to “map” the characteristics and volume of available research on this topic (Arksey and O'Malley, 2005, p. 20). It also provided the flexibility to include a breadth of peer-reviewed and non-peer-reviewed sources (Arksey and O'Malley, 2005). We followed the general steps for a scoping review outlined by Arksey and O'Malley (2005) with additional guidance on searching grey literature from Godin et al. (2015). See Figure 1 for an overview of the scoping review process.

We started by gathering relevant sources. Peer-reviewed articles were identified by searching Google Scholar and Academic Search Complete (Ebsco) databases. Key terms searched were Manitoba AND COVID-19 or pandemic AND “food security” or “food systems.” Given our emphasis on broader food systems, we did not use “food insecurity” as a key search term. A total of 384 peer-reviewed sources were identified.

Grey literature (e.g., reports, websites, policy documents) was identified through a Google search using the same search terms as above as well as directly searching the websites of the Manitoba government, provincial food-related organizations including Canadian Centre for Policy Alternatives (Manitoba Office), Harvest Manitoba, Food Matters Manitoba, Northern Manitoba Food, Culture and Community Collaborative, and Migrant Manitoba, as well as Statistics Canada and PROOF (Food Insecurity Research Institute) as key web sources for food security data. Media articles were not systematically searched but are drawn upon to contextualize findings from other sources. Recognizing it is impossible to review all grey literature results from the Google search, we relied on the “relevance” ranking of Google to identify a total of 129 sources (Godin et al., 2015).

We then screened all sources for inclusion. Only sources that focused on Manitoba or included Manitoba as a key component of a larger study were included. Sources that did not focus primarily on food security and COVID-19, such as those looking more generally at health and social-economic conditions during the pandemic, were excluded. This resulted in the vast majority of sources initially identified not being retained. For peer-reviewed articles, titles and abstracts were screened first; if it was unclear from the abstract if the study should be retained then the full text was screened.

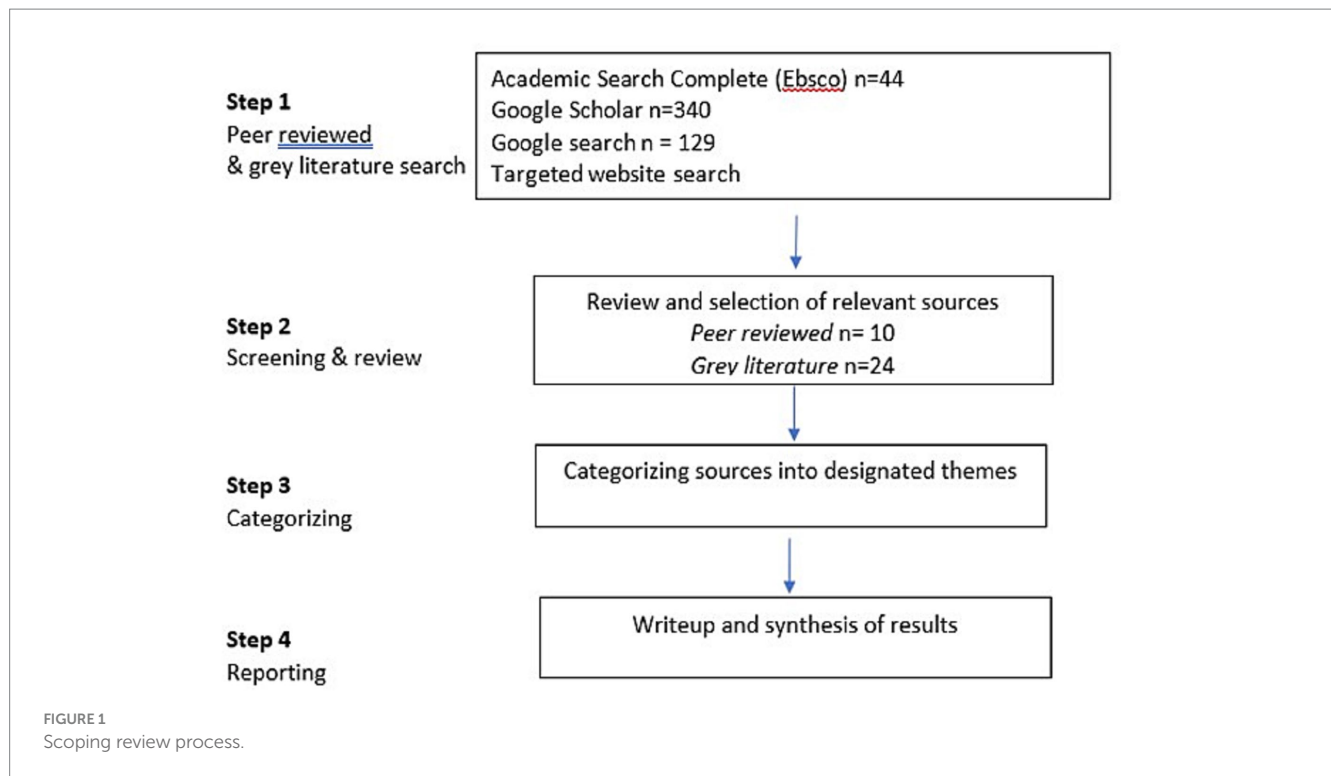
Altogether, 34 sources were retained for review including ten peer reviewed articles and 24 grey literature sources. Table 1 provides an overview of all sources by citation, category and key themes, and geographical focus. All sources were categorized according to the three key elements of the food security landscape previously elaborated by Lowitt et al. (2022) in their literature scan on food system pandemic impacts in Canada. These are: food security policy, funding, and programming; food security for individuals, households, and vulnerable groups; and food systems. Table 2 provides definitions of these categories. We used these categories as they were sufficiently broad to capture the range of sources and types of information included in our scoping review while also helping to promote thematic comparability of our findings with this previously published national literature scan. Within these categories, specific themes covered by the sources were identified from keywords in titles and abstracts and are also indicated in Table 1.

3 Results

In this section, we present our findings according to the key categories of: (1) food security policy, funding, and programming; (2) food security for individuals, households, and vulnerable groups; and (3) food systems.

3.1 Food security policy, funding, and programming

Twenty sources are included in this category, including seven peer reviewed articles and 13 grey literature sources. Various government initiatives in Manitoba were implemented in response to the pandemic. Table 3 provides an overview of these policy, funding, and programming responses according to provincial and joint provincial/federal policy initiatives.



The Manitoba government introduced a number of funding programs including a one-time Food Security Fund to address immediate food needs with funding mainly flowing to food banks and emergency meal programs. The provincial government also introduced a temporary relief program for the restaurant sector in collaboration with the Manitoba Chambers of Commerce and the Manitoba Restaurant & Foodservices Association. The Northern Healthy Foods Initiative received a one-time additional payment in spring 2022 to support local food production in Northern and remote communities affected by rising food costs partly tied to pandemic supply chain disruptions.

The Manitoba government also partnered with the federal government to deliver additional supports for food processors, distributors, and agri-food industry organizations. Of significance to local food systems, through the cost-shared Canadian Agricultural Partnership Program, \$160,000 was provided to Direct Farm Manitoba (a member-owned farmer direct marketing organization) to support e-commerce strategies for local food producers. As documented across the country, the pandemic contributed to a surge of interest in local food purchasing (Agri-food Analytics Lab, 2020) which this fund helped support in Manitoba. Larson (2020) also overviewed some of these public policies in the agriculture sector in Manitoba, calling for more proactive approaches to future pandemics.

Manitoba also benefited from various federal government policy supports. For example, the Canadian Emergency Response Benefit (CERB) provided income support for individuals whose employment was affected by the pandemic. Food banks and charities in Manitoba received support from the federal Emergency Food Security Fund and Surplus Food Rescue Program; for instance, through the latter program, \$1 million was allocated to Harvest Manitoba which they distributed through small grants to members of their community food

network across the province (Harvest Manitoba, 2023). The federal Emergency Processing Fund also supported some businesses in the provincial farming sector.

The provincial food retail sector was also involved in policy responses including through the government-led Manitoba Risk Recognition Program which provided one-time top-up payments to eligible essential workers including those employed in retail food and beverage. Two studies examined additional aspects of policy responses by food retail. Riediger et al. (2022) examined how the provincial grocery sector introduced new policies, such as those for employee health, safety, and operations, to minimize pandemic risks. Robinson et al. (2022) looked at how decision-making in response to pandemic risks in the foodservice industry in Winnipeg, Manitoba and other Canadian cities influenced sustainability policies.

Alongside government and private sector responses, the civil society sector in Manitoba was also active in communicating policy proposals, especially in the early months of the pandemic (see Table 4). Like the policy proposals put forward by civil society organizations nationally (see Lowitt et al., 2022), these proposals in Manitoba emphasized supporting those most vulnerable to food insecurity and addressing poverty as a structural cause. Indigenous food sovereignty was also a prominent theme in national policy proposals that was echoed in the statement by the provincial food security organization Food Matters Manitoba, including their calls to respect the autonomy of Indigenous Nations and for Indigenous-led food systems partnership development. Food policy councils in Winnipeg and Brandon – the two largest urban centres in the province – paid special attention to municipal and regional-level food system services and supports. Across the country, food policy councils played a key role early in the pandemic in advocating for local food infrastructure as an essential service (Food Communities Network, 2021).

TABLE 1 Sources included in the scoping review.

Citation	Category and key themes	Geographical focus
Peer reviewed (n = 10)		
Coulas et al. (2022)	Food security policy, programming, and funding; changes in school feeding program modalities	Newfoundland & Labrador, New Brunswick, Prince Edward Island, Nova Scotia, Quebec, Ontario, Manitoba, Saskatchewan, Alberta
Davidson-Hunt et al. (2022)	Food security policy, programming, and funding; community food security organization programming	Southern Manitoba and Kenora, Ontario
Gupta et al. (2022)	Food security policy, programming, and funding; school feeding programs and school reopenings	Newfoundland & Labrador, New Brunswick, Nova Scotia, Northwest Territories, Quebec, Ontario, Manitoba, British Columbia, Saskatchewan, Alberta
Larson (2020)	Food security policy, programming, and funding; government-led responses	Manitoba
Music and Charlebois (2022)	Food systems; consumer purchasing behaviour and online shopping	Across Canada including Manitoba
Riediger et al. (2022)	Food security policy, programming, and funding; policy responses in food retail	Manitoba
Robinson et al. (2022)	Food security policy, programming, and funding; sustainability policies in foodservice	Winnipeg (Manitoba), Vancouver (British Columbia), and Orillia (Ontario)
Slater et al. (2022)	Food security policy, programming, and funding; food charity programming	Manitoba
Smith et al. (2023)	Food systems; consumer grocery shopping behaviour pre and during pandemic	Winnipeg, Toronto, Ottawa-Gatineau, Montreal, Calgary, Vancouver, Halifax, and Saskatoon
Sousa et al. (2020)	Food systems; production and consumption impacts	Manitoba
Grey literature (n = 24)		
Charlebois et al. (2023)	Food security for individuals, households, and vulnerable groups; food prices	Across Canada including Manitoba
Engage Manitoba (n.d.)	Food systems; agri-food data	Manitoba
Food Communities Network (2021)	Food security policy, programming, and funding	Across Canada including Manitoba
Food Matters Manitoba (2020a, April 23)	Food security policy, programming, and funding	Manitoba
Food Matters Manitoba (2020b, May 20)	Food security policy, programming, and funding	Manitoba
Funk and Li (2021)	Food systems; community gardens	Manitoba
Government of Canada (2020, October 15)	Food security policy, programming, and funding	Manitoba
Government of Manitoba (2022, September 26)	Food security policy, programming, and funding	Manitoba
Government of Manitoba (2021a, April 16)	Food security policy, programming, and funding	Manitoba
Government of Manitoba (2021b, April 16)	Food security policy, programming, and funding	Manitoba
Government of Manitoba (2020a, August 4)	Food security policy, programming, and funding	Manitoba
Government of Manitoba (2020b, July 20)	Food security policy, programming, and funding	Manitoba
Government of Manitoba (n.d.-a)	Food security policy, programming, and funding	Manitoba
Government of Manitoba (n.d.-b)	Food systems	Manitoba
Hajer and Fernandez (2021)	Food systems; funding	Manitoba
Harvest Manitoba (2023)	Food security policy, programming, and funding	Manitoba
Harvest Manitoba (2022)	Food security for individuals, households, and vulnerable groups	Manitoba
Harvest Manitoba (2021)	Food security for individuals, households, and vulnerable groups; food bank usage	Manitoba
Northern Manitoba Food, Community, and Culture Collaborative (2022)	Food security for individuals, households, and vulnerable groups	Manitoba
Plaut (2020)	Food security policy, programming, and funding; community organizations	Manitoba
Statistics Canada (2020a)	Food security for individuals, households, and vulnerable groups	Across Canada including Manitoba
Tarasuk et al. (2022)	Food security for individuals, households, and vulnerable groups	Across Canada including Manitoba
Winnipeg Food Council (2020a, May 20)	Food security policy, programming, and funding	Manitoba
Winnipeg Food Council (2020b)	Food systems; victory gardens	Manitoba

TABLE 2 Categories of analysis adapted from Lowitt et al. (2022).

Category	Definition
Food security policy, funding, and programming	Pandemic responses from the government, private sector, and civil society
Food security for individuals, households, and vulnerable groups	Food access during the pandemic
Food systems	Broader changes posed by the pandemic to provincial agri-food systems spanning production, labour, transportation, and consumer behaviour

TABLE 3 Responses from the provincial and federal governments.

Program	Purpose	Citation
Manitoba		
Food Security Fund	Support for community organizations addressing immediate food needs (\$1.75 million)	Government of Manitoba (2022, September 26)
Northern Healthy Foods Initiative	One time increase to address food pressures related to the pandemic (\$193,000)	Government of Manitoba (n.d.-a)
Dine-in Restaurant Relief Program	Relief program for restaurant owners and operators to cope with pandemic challenges (\$5 million)	Government of Manitoba (2021a, April 16)
Manitoba Risk Recognition Program	One-time payment to essential workers, including those in food retail and beverage (\$120 million)	Government of Manitoba (2020a, August 4)
Home Nutrition and Learning Program	Support for weekly food boxes and educational resources to families with school-aged children experiencing food disruption (\$7.1 million)	Government of Manitoba (2021b, April 16)
Joint federal-provincial		
Canada-Manitoba Finished Cattle Feed Assistance Program	Support for cattle farmers in Manitoba to cope with pandemic challenges, including operational reductions and slaughter plant closures (\$2.5 million)	Government of Canada (2020, October 15)
Cost-shared Canadian Agricultural Partnership Program	Support for Manitoba agri-food processors, distributors, and industry organizations to mitigate spread of COVID-19 (\$3 million)	Government of Manitoba (2020b, July 20)

TABLE 4 Policy proposals from civil society organizations.

Organization	Policy statement	Citation
Brandon Food Policy Council	Food Security COVID-19 Joint Policy Statement	Food Matters Manitoba (2020a, April 23)
Winnipeg Food Policy Council	Winnipeg Food Policy COVID-19 Statement	Winnipeg Food Council (2020a, May 20)
Food Matters Manitoba	COVID-19 Food Security Call to Action	Food Matters Manitoba (2020b, May 20)

Lastly, as experienced across the country, programming changes took place within community food security organizations in the province. Plaut (2020) documented how community-based organizations responded and mobilized their networks to continue serving vulnerable residents in inner city Winnipeg, such as opening new food distribution centres in public spaces. Davidson-Hunt et al. (2022) similarly documented organizational responses among community food organizations in southern Manitoba, emphasizing the importance of pre-existing relationships and connections in place to supporting food needs. Slater et al. (2022) described changes to the provincial charitable food sector during the first wave as it reconfigured delivery and other programming aspects to meet rising needs while government funding was slow to roll out. Coulas et al. (2022) and Gupta et al. (2022) described how school food programs in Manitoba and across Canada adapted programming models to continue serving children and their families. Of note, Coulas et al. (2022) identified Manitoba as one of the few provinces to expand food

programs within schools since September 2020 as part of school reopening efforts following pandemic closures. A range of media articles in Manitoba further detailed these changes in community food programs (for example see CBC News, 2020a, April 23; CBC News, 2020c, Dec. 4).

3.2 Food security for individuals, households, and vulnerable groups

Six sources from grey literature are included in this category. Food security data for Manitoba are collected through national surveys, including the Canadian Community Health Survey (CCHS) and Canadian Income Survey (CIS). There is evidence from a national web survey that food insecurity across the country increased in the early months of the pandemic mainly due to disruptions to employment income (Statistics Canada, 2020a). Harvest Manitoba (2021) likewise reported a 30% increase in food bank usage in March 2020, with female and Indigenous clients especially seeking assistance.

However, using data from the CIS, Tarasuk et al. (2022) estimated that, overall, food insecurity in Manitoba and across Canada was fairly stable from 2019–2021. This has been at least partly attributed to pandemic government income supports (Polysky and Garriguet, 2022). For 2021, the most recent year for which food security data are available at time of writing, Tarasuk et al. (2022) estimated the prevalence of food insecurity at 17.8% in Manitoba, slightly higher than the 15.9% average across provinces (Tarasuk et al., 2022). Significantly, this figure is likely an underestimation since on-reserve

First Nation households, a group vulnerable to food insecurity, are excluded from these national surveys (Tarasuk et al., 2022). Addressing this data gap in Manitoba is especially important because Indigenous peoples comprise approximately 18% of the population, the highest of any province (Statistics Canada, 2020b), with nearly 60% of this population living on reserve (Government of Canada, 2021a).

It is likely that food insecurity will be higher in 2022–23 due to inflation of food and other goods (Tarasuk et al., 2022). Since early 2022, pandemic-induced supply chain disruptions have interfaced with rising input costs in global agriculture and extreme weather events to increase food prices in Manitoba and across Canada (Charlebois et al., 2023). Indicative of these rising costs, Harvest Manitoba reported a 40% year over year increase in demand for services by the end of March 2022 (Harvest Manitoba, 2022).

We found only one source that specifically examined food insecurity among northern Indigenous communities in Manitoba during the pandemic. The Northern Manitoba Food, Community, and Culture Collaborative (2022) documented food access challenges and strategies across northern Indigenous communities in 2020–21. They described shortages and higher prices of retail foods due to lockdowns and transportation restrictions and delays and noted that one of the main community responses was increased sharing of traditionally harvested foods and medicines. The lack of sources in this area is a notable gap given the long-standing food security vulnerabilities northern Manitoba communities face related to high food prices, poverty, and climate change, all stemming from settler-colonial policies (Rudolph and McLachlan, 2013; Wendium et al., 2018).

3.3 Food systems

Eight sources are included in this category, including three peer reviewed articles and five grey literature sources. Findings are presented according to the key themes of labour and production, local food systems, and consumer behaviour that emerged across these sources.

3.3.1 Labour and production

Sources in this theme indicate that the pandemic worsened labour shortages in Manitoba's agri-food sector and especially the labour-intensive meat processing and horticulture sectors (Sousa et al., 2020; Government of Manitoba, n.d.-b). As documented by Sousa et al. (2020), this was partly tied to travel restrictions and self-isolation and quarantine measures that affected Temporary Foreign Workers (TFWs), resulting in some short-term disruptions to food production. COVID-19 outbreaks were a particular problem in meat processing plants, as documented by Sousa et al. (2020) and widely reported in the media (see CTV News, 2020, August 10; CBC News, 2020b, June 4). These outbreaks disproportionately affected the TFWs who were a key part of the labour force in these plants (Sousa et al., 2020). A report by the Office of the Auditor General for the Government of Canada (2021b) found that health and safety protections were inadequate for TFWs across the country during the pandemic.

3.3.2 Local food systems

Several sources considered opportunities for local food systems development. Sousa et al. (2020) argued for greater support for localized production due to global supply chain disruptions as well as further engagement with Northern and remote communities to

support their unique food system needs. Hajer and Fernandez (2021) also called for more funding support for local agricultural production with linkages to community economic development goals, situating their call in a critique of the austerity of provincial government economic policy leading up to the pandemic. These arguments in support of local food systems development are reinforced by results from a 2021 survey by Manitoba Agriculture and Resource Development which demonstrated strong public support for local food systems during the pandemic, including a preference for purchasing Manitoba grown foods (Engage Manitoba, n.d.). Lastly, two reports were published about the Meadowood Victory Garden in Winnipeg, sharing lessons learned for urban gardening from the pandemic and highlighting opportunities to scale up gardens for future community benefits (Winnipeg Food Council, 2020b; Funk and Li, 2021). This interest in local food systems in Manitoba reflects a turn towards local food systems documented across the country during the pandemic (Lowitt et al., 2022).

3.3.3 Consumer behaviour

Changes to consumer behaviour in Manitoba were documented by two sources. Music and Charlebois (2022) looked at how some Manitobans switched to online shopping during the pandemic driven by convenience and safety, despite the sometimes-higher cost. This behaviour is consistent with national trends that showed greater e-commerce distribution during the pandemic (Charlebois and Music, 2020). Smith et al. (2023) investigated grocery shopping patterns in Winnipeg, Manitoba and other large Canadian cities and found, among other trends, a decline in the number of trips and stores visited compared to pre-pandemic.

4 Knowledge gaps and opportunities for future research and policy

Emerging from this scoping review, we conclude by identifying priority areas for research and practice that may support equitable and resilient food systems in Manitoba. These priority areas include: (1) undertaking evaluation of food system policies, programs, and funding implemented during the pandemic (2) enhancing food security monitoring for vulnerable populations (3) further exploring community experiences and responses to food security; and (4) examining opportunities for local food systems development.

First, research and analysis will be important to evaluating the impacts of pandemic policies, funding, and programming on different sectors and populations of the food system. While our review has documented the funding that came online and programming and policy changes that occurred within food security organizations and sectors, we found very little literature evaluating the impacts of these pandemic measures in Manitoba. This evaluation is crucial to informing what worked well, less well, and to what extent programs and policies effectively met their stated objectives and effectively reached those in need of support. This evaluation is important not only to strengthening resilience to future pandemics but learning from COVID-19 responses for other stresses like climate change and food inflation (Biosfi et al., 2021).

Second, there is a need for enhancing food security monitoring for vulnerable populations. There are known data gaps in national food security surveys that exclude on-reserve Indigenous populations and

this is particularly significant in Manitoba because of the high proportion of Indigenous people in the population. Further, while data exists for the province as a whole, food security data for Manitoba stratified by characteristics such as race/ethnicity, gender, and age would paint a fuller picture of food access in the province. This would include how food insecurity overlaps with other potential markers of socio economic disadvantage (Tarasuk et al., 2022). A survey of adolescents in Manitoba conducted pre-pandemic showed a 20% incidence of food insecurity; however, this was almost double (37%) in the northern region of the province (Canadian Institute of Health Research and University of Manitoba, 2023). Recent food price volatility and inflation point to the need for ongoing surveillance and monitoring of food security rather than the current patchwork approach.

Third, there are opportunities to further explore community experiences and responses to food insecurity during the pandemic. There is some evidence from our review of the importance of community partnerships and place-based connections in enhancing local resilience in the face of crisis. Future strength-based research that centres community assets and engages community members in articulating their perspectives and visions will be important to developing holistic understandings of food security and ensuring the fit of policies and programming with community assets and needs (Soma et al., 2022). A specific opportunity for future research building on this scoping review is to systematically examine news and social media that may offer further insights into community strategies for resilience building during the pandemic.

Finally, examining opportunities for local food systems development is a recommendation emerging from this review. There is some evidence from our review of high public support for local food systems in Manitoba during the pandemic with some authors positioning local food systems as a key component of regional economic development and stability in food supply. These findings are reinforced by a recently published “snapshot” of Winnipeg’s food system, outlining immediate and long-term goals for local food systems development (Winnipeg Food Council, 2022). Attention to the poor working conditions of food system labourers, and especially Temporary Foreign Workers in meat processing, also gained greater public attention during the pandemic. Addressing precarious work for the province’s food system labour force will be a critical step in more equitable regional development and food systems stability.

To what extent increased interest and awareness in local food systems during the pandemic, including innovations in online local food purchasing and increased urban gardening, may translate into long term practice will be important to follow. Also of significance to local food systems is the pressing need for culturally appropriate and

community-driven solutions for northern Indigenous communities as highlighted by Northern Manitoba Food, Community, and Culture Collaborative (2022) and Sousa et al. (2020). For these communities, inequities in food access were further exposed by the pandemic underscoring the need for decolonizing food systems as long called for among Indigenous scholars and food security advocates in the province (Wendium et al., 2018) and being increasingly voiced nationally (Levkoe et al., 2021; Mashford-Pringle et al., 2021).

In sum, our scoping review has synthesized the impacts of COVID-19 on food systems in Manitoba and identified some priority areas for research and practice that we hope can inform efforts towards resilient and equitable food systems in a period of COVID-19 recovery and ongoing food system stresses.

Author contributions

KL and JS contributed to conception and design of the study. ER organized the scoping review materials. KL wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The paradox of corporate sustainability: analyzing the moral landscape of Canadian grocers

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Food prices have experienced unprecedented increases in recent times. Simultaneously, grocers are facing allegations of capitalizing on inflation to generate unjustifiable profits. Escalating expenses and a lack of transparency have engendered heightened consumer skepticism. This perceived presence of barriers and excessive profitability gives rise to ethical concerns. Our case study delves into the ethical landscape surrounding Canadian grocers, aiming to probe the public's demand for accountability. To comprehend the factors responsible for the transformation in consumer perception of Canadian grocers in 2022, we conducted an analysis utilizing data from consumers, corporate watchdogs, and industry sources. We extended the paradox perspective on corporate sustainability framework to include a historical aspect to use as our analytical lens. This study sheds light on the alterations in circumstances that have led Canadian consumers to question entire industries and accounting practices that were previously considered unproblematic. As a remedy, we recommend the establishment of a mandatory code of conduct for grocers and an enhancement in the transparency of financial reporting. Paradoxically, corporate profits may continue to grow when societal needs are no longer perceived as being neglected or, even worse, exploited.

KEYWORDS

food policy, retailing, economic growth, inflation, corporate sustainability, accounting, financial reporting

Introduction

Commodity prices are surging at levels unprecedented in decades. Consequently, political analysts are attributing this phenomenon to Canada's major supermarket chains, alleging their engagement in "Greedflation"—which can be defined as the deliberate exploitation of inflationary trends to generate excessive profits (1). "Greedflation" pertains to the perception that soaring prices are driven by unjustifiable or morally questionable factors. Simultaneously, food inflation has reached historic highs.¹ All three major Canadian grocers outperformed their average performance, with one grocer having its best year ever (3). Does this mean Canadian grocers are guilty of "Greedflation"?

1 "In September, prices for food purchased from stores (+11.4%) grew at the fastest pace year-over-year since August 1981 (+11.9%). Prices for food purchased from stores have been increasing at a faster rate than the all-items CPI for 10 consecutive months, since December 2021" (2).

Some may contend that corporate profits are ethically contentious, as they represent the residual ownership share enabling the accumulation of passive income among the ownership class. Further, Svanberg and Svanberg (4) advocate that “to the degree, business ethics shares the conventional perspective, it will face a problem justifying the crux of business; the bottom line.” As labor is required to produce residual income for the owner class, the passive income for one individual represents the lost wages of another.

In their paper, Svanberg and Svanberg (4) revealed that conventional ethics may deem only the means of conducting business as potentially morally justifiable, while not necessarily extending the same ethical judgment to the profits generated. Nonetheless, it is important to acknowledge that disentangling profits from the business itself may present significant practical challenges. Lee (5) advocates for the implementation of policies aimed at enabling firms to maximize their appropriation of the positive externalities arising from their innovations. This approach is intended to enhance the incentives for prospective innovators. It is plausible to argue that corporate profitability plays a pivotal role in driving innovation, even in critical domains such as food safety.

To illustrate this point, consider a contrasting scenario where market conditions are characterized by reduced income levels and limited resources for investment and profit accumulation. In such circumstances, low and middle-income countries may find themselves grappling with foodborne diseases stemming from the consumption of fresh perishable foods, particularly those sold within informal markets.

The connection between corporate profit and innovation is multifaceted, with implications extending beyond conventional economic metrics. By fostering an environment in which firms can effectively harness the positive externalities of their innovations, policymakers can bolster the impetus for future advancements, which may include critical areas like food safety. Conversely, in markets where profit margins are constrained, there exists a heightened risk of suboptimal outcomes, as exemplified by the prevalence of foodborne illnesses in less affluent regions (6).

The moral landscape is a concept that “addresses the interrelationship between landscapes and moral values and judgments” [(7), 191], and is “a hypothetical space representing human well-being [...] where the peaks of this landscape are the heights of prosperity, and the valleys represent human suffering” (8) [as cited in Diller and Nuzzolilli (9), 266]. This paper uses the term “moral landscape” in conjunction with paradox perspective on corporate sustainability framework of Hahn et al. (10) to analyze the peaks and valleys of Canadian grocers and their stakeholders.

Canada employs a mixed-market system primarily characterized by free-market principles. However, the federal government does exercise control over certain services, such as postal and air traffic control. Additionally, the Canadian system exhibits certain features akin to a socialist system, exemplified by the provision of retirement benefits and universal healthcare coverage (11). A free-market system, also known as capitalism, is characterized by the ownership and operation of most businesses by individuals who possess their assets and retain their post-tax profits (*ibid*). However, in the current context of soaring food prices, ethical concerns have emerged regarding the sale of food and the practices of Canadian grocers. There is a lack of consensus regarding an acceptable profit threshold within this sector. In the broader business landscape, corporate leadership remains

divided on what constitutes ethical conduct when it comes to earnings management (12).

Three major companies dominate Canadian food distribution to consumers (13). These companies operate diverse businesses that encompass food reporting, apparel, beauty, health (including pharmaceuticals), and other general merchandize, all consolidated within a single category. Present reporting standards allow companies with operations sharing similarities in nature, production, or sales to aggregate their financial data. Consequently, this practice renders it challenging, if not entirely unfeasible, to accurately assess profitability solely based on food sales. In the context of an investor call with financial analysts, one president of a grocery chain attributed their increased margins to higher-margin products such as fragrances. When a member of the media sought validation of the grocer's statement from an accounting professor, the professor indicated that it was impossible to either confirm or refute the statement using the publicly available information in the financial statements (14). Without greater transparency, it remains challenging to determine whether Canadian grocers have engaged in consumer price gouging.

The escalation in prices and the absence of transparency have contributed to a heightened sense of consumer distrust, with more than two-thirds of Canadians perceiving grocers as capitalizing on inflation to impose exorbitant pricing (15). Food constitutes a fundamental human necessity, with other essential requirements such as warmth and shelter being subject to direct regulation or significant government policy influence in Canada. Various components of the Canadian food distribution system fall under substantial regulatory oversight within the country. The Canadian Health Food Association delineates these regulations through three key legislative acts, namely the Food and Drugs Act, Safe Food for Canadians Act, and Consumer Packaging and Labeling Act (16). These acts ensure Canadians have transparent data (labeling, advertising, and claims) to make informed food decisions.

While certain Canadian products, such as dairy and poultry, are subject to government regulation, including domestic production controls, wherein farmers are able to recover the costs of production (17), Canada does not currently have regulations dictating the prices that grocers charge to consumers (17). Although price ceilings may appear to address immediate concerns, implementing price ceilings on food items could potentially diminish consumers' access to fresh produce, hinder innovation, and limit investments in research (17). Perhaps greater competition and increased food innovation are necessary to address the issue of food inflation in Canada. This may be a key rationale behind the Competition Bureau Canada's decision to initiate a study into grocery prices. When addressing this inquiry, the Competition Bureau Canada noted, “There are differing perspectives on the causes of these price increases. Some contend that inflation has escalated the cost of goods for grocers, leading to higher prices. Conversely, others argue that grocers are setting higher prices due to a lack of sufficient competition in the market” (18). The Competition Bureau of Canada has articulated the primary objective of its investigation as the pursuit of a deeper comprehension of pertinent issues. The aim is to identify strategies and measures that Canada can undertake to facilitate the competitive and innovative capacities of emerging enterprises (18).

The investigation into how Canada can assist competition (and thus, manage prices) and food innovation may result from a lack of action by the Competition Bureau Canada to date. In 1998, Loblaw's

acquired Provigo (19), in 2005, Metro acquired A&P (20), and in 2013, Sobeys acquired Safeway (21). In 2021, Loblaw, Metro, and Sobeys had over \$100 billion in annual revenues (22) and were responsible for most food sales in Canada (13). Similar consolidations have faced scrutiny and may not be permitted elsewhere. In the United States, grocer consolidation faces opposition to reducing the likelihood of oligopolistic industries. Kroger (23) was trying to acquire Albertsons for approximately \$25 billion and become the second-largest grocer in America (24). United States regulators have pushed back and may require the divestiture of a sizeable number of stores, effectively ensuring a competitive market is maintained, an action that both companies say they are willing to make to complete this proposed deal (25). In Canada, consumers are left to ponder whether grocery retailers are exploiting the unprecedented surge in inflation to impose prices that exceed a justifiable increase. Consumers harbor inquiries and apprehensions but find themselves unable to procure satisfactory responses.

Current research indicates that, in the realm of policy matters, manufacturers tend to be perceived as more accountable than farmers and retailers (26). However, recent record-high inflation and the current rise in consumer distrust on popular and social media outlets have signaled that consumer concern may be shifting toward grocery retailers.

The primary objective of our study is to conduct an ethical analysis of the Canadian grocery industry, with a specific focus on examining the moral dimensions of grocers' conduct. This research seeks to delve into the growing public demand for greater accountability within the industry and, consequently, aims to put forth actionable recommendations to enhance transparency. Notably, the profitability of the grocery sector has hitherto received limited comprehensive scrutiny, making this investigation particularly significant. The unprecedented rise in food prices has raised ethical questions among Canadians, prompting inquiries into whether it is morally justifiable for grocery retailers to reap substantial financial gains while consumers face the challenges of limited alternatives for meeting their essential needs. This study aims to shed light on these critical ethical concerns.

In our study, we investigate the following research question: how have stakeholders perceived the economic consequences of rising food inflation? To examine the complex interplay between profitability and societal welfare, we adopt a paradoxical approach to corporate sustainability. Our investigation focuses on the Canadian economy as a case study to shed light on the escalating tensions between retailers and consumers. In this pursuit, we employ descriptive, instrumental, and normative dimensions of corporate sustainability (10) to observe and understand the moral landscape of the Canadian grocer oligopoly.

We aim to elucidate the factors responsible for the shift in consumer perception of Canadian grocers in 2022. Our analysis encompasses consumer data, corporate watchdog reports, and industry data, with the goal of proposing solutions to bolster trust and improve social and economic well-being within the Canadian grocery landscape. This research seeks to make the following significant contributions. Firstly, we intend to shed light on the evolving conditions that led Canadian consumers to lose trust in entire industries and accounting practices, which had previously not raised concerns. Secondly, we will explore the availability of information to consumers and the limitations therein.

Finally, we will put forth a recommendation for a mandatory grocer code of conduct, encompassing enhanced financial reporting, and conclude by outlining avenues for future research.

The structure of our paper is as follows: In section 2, we will delve into the conceptual framework, which comprises three key antecedents essential to understanding the moral landscape of Canadian grocers—namely, inflation, consumer trust, and the social aspect of sustainability. This will be followed by an explanation of our case study methodology and the specific factors we examined in section 3. Section 4 will present our findings, with the subsequent discussion taking place in section five. We will conclude by offering recommendations for formal agreements and increased transparency to aid grocers in regaining the trust of Canadians. It is our contention that through reestablishing this trust, grocers can not only enhance their positive social impact but also potentially, paradoxically, bolster their net profits, inflationary context, and consumer trust.

To address the tensions between grocers and consumers, we look to first understand the economic, behavioral, and financial antecedents to this conflict.

Inflation

Hart (27, p. 8) defines inflation as “a process that raises price levels” and “defining it like this, we can graft on adjectives to describe the intensity or mechanism of particular kinds of inflation.” When discussing the consumer market, Glushchenko (28, p. 69) defines “official inflation” as “the growth of the overall level of consumer prices.” He then listed the limitations of its measurement, including a consumer basket of goods often ignores items only purchased by the wealthy. That inflation based on a basket of consumer goods does not directly reflect a “real” reality. An example presented by Glushchenko was if one in 100 people purchase a television set, then one 100th of a television will be in the basket, and that number will be divided by 12 to represent monthly inflation. That “basket of goods” is referred to as the Consumer Price Index (CPI), and each country has its measurement of CPI.

The CPI basket of goods is not static, as evolving societal norms influence consumer preferences. Items that were once deemed luxurious, such as film cameras, may now constitute typical household expenditures (27). Moreover, inflation metrics have failed to account for the fact that consumer packaged goods have diminished in size, for instance, with some products offering fewer chips or a reduced weight compared to their previous iterations.

To communicate the direction and magnitude of rising inflation, adjectives such as “creeping,” “galloping,” and “hyper” may be used (27). Hart likened the latter term, hyperinflation, to prices rising so fast that the purchasing power used to buy commodities would quickly evaporate off the paper money. When identifying inflationary terms and conditions that may harm society, Temple (29) found that while there is no evidence that moderate inflation can inhibit growth, high inflation, defined as over 100% per year, does inhibit growth. Regardless of the amount of inflation, Shaw (30) suggests it is society's democratic institutions, not the private sector, who should deal with “national agenda issues” like inflation, pollution, and unemployment.

While inflation can be mitigated through systemic policy decisions, the escalation in prices of specific products imposed by corporations on consumers can significantly influence consumer trust.

Consumer trust

Behavior often drives action. Sirdeshmukh et al. (31) adopted definition of consumer trust of Moorman et al. (32) as a “willingness to rely on an exchange partner in whom one has confidence.” To understand the different types of exchange partners consumers may rely on in the food industry, we look to the literature. Wu et al. (33) find consumer trust in food and the systems that govern food distribution to be tied to both individual food items (i.e., through packaging labels, certifications, country of origin, and food traceability) and with producers, processors, and retailers providing consumers with food safety. The authors acknowledge that government agencies, third-party institutions, advocacy groups, and the media impact how consumers perceive labeling information and how food operators, including grocery retailers, are viewed by consumers.

Consumer mistrust in the food system can impact consumer purchasing behavior. Nuttavuthisit and Thøgersen (34) found that consumers’ mistrust in the food control system had a significant negative impact on purchasing organic food. Further, Macready et al. (26), in our study, we discovered that consumers’ trust in participants within the food supply chain is contingent upon their perception of the participants’ competence, level of care, and degree of openness. When consumers lack confidence in a participant, such as a grocery retailer, demonstrating care, and transparency in their actions, it results in a corresponding erosion of trust among consumers. Similarly, Rampl et al. (35) found integrity as a driver of consumer trust of food retailers.

It is crucial to examine the connections between consumer perception and consumer trust. Research has demonstrated that the emotional attachment between consumers and firms significantly impacts consumer loyalty and word-of-mouth communication (36). They found that place identity was a predictor of emotional attachment. Therefore, it is reasonable to investigate whether a negative place identity (e.g., associated with a grocery retailer) would diminish a consumer’s emotional attachment and subsequently reduce their purchasing loyalty and positive word-of-mouth behavior.

In numerous countries, such as Canada, utilities undergo strict regulation, accompanied by regulations pertaining to housing affordability and housing choice. Conversely, the food retail sector, for the most part, remains unregulated. During periods of mounting financial stress and diminishing consumer trust, the potential consequences on society become more pronounced as families grapple with the challenge of providing sustenance for their loved ones amidst rising corporate profits, potentially resulting in an increasingly adverse social impact.

Social impact

Corporate social responsibility (CSR) means going beyond financial performance and shareholder interest (10). Given the link between managing systematic risk, portfolio value, and CSR (37), investors want reliable and transparent disclosures to aid in their investment choices.

International investment stakeholders have called for transparent and reliable reporting that goes beyond financial accounting—they want standards on environmental, social, and governance (ESG). As a result, in late 2021, the International Financial Reporting Standards

(IFRS) Board announced a new standards board, the International Sustainability Standards Board (ISSB) (38). The ISSB was created to deliver a global baseline for ESG disclosures to ensure international investment stakeholders have a complement of financial and sustainability measures to assist their decision-making process.

Similar appeals for greater openness among participants in the food chain to furnish pertinent information and enhance transparency are not novel. The need for heightened transparency may arise in response to product crises or deliberately engineered events. For instance, enhanced labeling transparency emerged as a response to Canada’s mad cow disease (39) and the manufactured case of salmonella (40). However, what is relatively new is the extension for the call for transparency beyond personal crises toward overall transparency prior to a specific incident (26). It is at that system level that Bansal (41), as summarized by Hahn et al. (10), defined corporate sustainability as “the intersection of the three principles: environmental integrity, social equity, and economic prosperity.”

Previous research has often framed sustainability as a “business case,” focusing on the analysis and discussion of financial outcomes as the primary metric of success, with environmental, social, and governance (ESG) considerations seen as a “cost” that could potentially have a negative impact on a company’s financial performance (10). In contrast, the paradox perspective of sustainability encourages the consideration of the intrinsic value of multiple metrics beyond their direct and immediate impact on the company’s bottom line (10). Hahn et al. (10) discovered that adopting a paradox perspective and evaluating sustainability in terms of descriptive, instrumental, and normative aspects led to superior contributions to business success.

When examining the three dimensions of the paradox perspective on sustainability, the descriptive dimension serves the purpose of both “describing and explaining” sustainability issues, which aim to “capture organizational phenomena surrounding such tensions” [(10), p. 240]. The instrumental dimension establishes connections between determinants and outcomes, encompassing both short- and long-term consequences. In contrast, the normative dimension encourages corporations to be accountable beyond mere financial returns and shareholder concerns, potentially contributing to a broader discourse on the role of business in sustainable development (10).

When consumers are informed that rising grocery store costs are attributed to inflation, without accompanying empirical evidence to either substantiate or refute the claims made by grocers, it exacerbates tensions among consumers, corporate watchdogs, and the retail grocery industry. The prevailing dominant culture and historical lack of transparency in financial reporting are now being challenged more vigorously than ever before.

There is a social and moral impact of consumers facing increased costs to purchase food and provide their families with nutritious meals. The total annual cost of diet-related chronic disease in the United States exceeds 1 trillion dollars (42). Research published in the *Journal of the American Medical Association* found that in the United States, there are nearly 1,000 deaths per day linked to cardiovascular and diabetes disease, with poor diet contributing factors (43). Food insecurity not only has immediate negative consequences but can also lead to long-lasting health and societal impacts.

In order to address the existing tension between Canadian grocers and consumers, our research endeavors to answer the following research questions: How do stakeholders perceive the economic impact of the rising food inflation?

We approach the examination of the conflict between corporate profits and societal welfare through the lens of the paradox perspective on corporate sustainability. To assess the escalating conflicts between grocers and consumers, as well as the role played by industry watchdogs, we employ the descriptive, instrumental, and normative dimensions of corporate sustainability.

This approach allows us to closely examine and comprehend the ethical landscape within which Canadian grocers operate. The tension between consumers and grocers encompasses economic, behavioral, and financial components, and mitigating this tension may yield positive social outcomes. Consequently, we proceed with our analysis of the ethical framework surrounding Canadian grocers.

Materials and methods

Pragmatism philosophy guides our research methodology (44). We employ an abductive approach, whereby our case study strategy is operationalized by mixed-methods (44) over a longitudinal time horizon and focused on the grocery industry to investigate the evolving consumer perception and trustworthiness of Canadian grocers. Canada's food retail sector is primarily dominated by five major grocery retailers, three of which are Canadian public companies collectively generating an annual revenue exceeding 100 billion dollars. In our study, we will specifically examine the Canadian public company grocer retailers, namely Loblaw Companies Limited (referred to as Loblaw), Empire Company Limited (the exclusive owner of Sobeys Inc., referred to as Empire/Sobeys), and Metro Inc. (referred to as Metro), which are the three largest Canadian public grocers.

We utilized various techniques and procedures for our case study research strategy while collecting our data and performing analysis (45). When using a case study strategy, Yin (45), as cited by Eckhardt and Dobscha (46), recommends collecting data that includes annual reports, popular media and press releases, and observations of corporate leadership through published interviews. Additionally, we used Interim financial reports to examine current information.

We conducted a comprehensive review of communication from corporate watchdogs. Utilizing capital market data and custom algorithms, we evaluated the relative financial performance, including capital gains and total market returns, of various grocery retailers. Our analysis involved benchmarking their performance against the overall stock market for the period spanning from 2017 to 2022.

Starting with the paradox perspective framework on corporate sustainability (10), we extended the model to include a historic perspective, such that our findings are organized using Canadian grocers' historical, descriptive, instrumental, and normative aspects. Our analysis focused on the social and financial outcomes of Canadian grocers.

Through data collected from consumers, corporate watchdogs, and retailers, we analyzed the moral landscape of Canadian grocers to understand how stakeholders experienced the impact of increased food inflation.

Findings

We extend model of Hahn et al. (10) to include a historical aspect to analyze the paradox perspective framework of corporate

sustainability, as outlined in our conceptual model in Figure 1. As such, our findings are organized according to the aspects in this model: historical, descriptive, instrumental, and normative.

Historical

The history of the Canadian grocery industry is marked by a story of consolidation. The prominent players in today's landscape were not always the expansive and dominant entities they are now, nor did they always possess the substantial market share they currently hold. The origins of Canada's modern grocery giants would appear quite unfamiliar to today's consumers. In this article, we provide a concise historical overview of the industry, organized as follows: we begin with an overview of key historical facts, followed by an examination of the market dynamics and regulatory pressures that led to the market entries and mergers. We conclude by drawing a comparative analysis with the grocery industries in the United States and the United Kingdom.

Historical facts

We can briefly summarize the history of Canada's major grocers to gain insight into their current market positions. Loblaw and Sobeys originated as limited-offering grocers around the conclusion of the First World War and underwent substantial expansion following the Second World War.

Loblaw began with a cash and carry model for grocery in 1919, adding today's well known staples such as meat and produce in 1933 (47). Similarly, Sobeys began offering a full line of produce to customers in 1924 (48). In 1947, a handful of grocery buyers joined together as Lasalle Stores Ltd., (later becoming Metro in 1972) (49).

Loblaw was incorporated in 1956, joining stores in Ontario and the United States into a single entity (50). In 1961, Giant Tiger was founded (51). Purchases then continue to fuel moderate expansion by the three major grocers, but major mergers, market entries, and acquisitions are rare between 1960 and 1980. In 1985, Costco joined the Canadian Market, opening its first store in British Columbia (52). Walmart subsequently entered Canada in 1994 with its purchase of Woolco Stores in Canada (53).

By the mid-1990s, the major grocers' operations are highly resemblant of their current day businesses. What remains are the major acquisitions of the 1990, 2000, and 2010s. 1998 was a significant year for the industry in Canada. It was then when Sobeys purchased Oshawa Group (which included most IGA stores), and when Loblaw purchased Provigo (19). With well-established market positions, the grocers intensified their diversification of product offerings in regard to food [for example, the (53) purchase of T&T, an Asian grocery chain (54)].

Very recent merger and acquisition activity has only increased the degree of consolidation, with high profile acquisitions such as the purchase of Safeway by Sobeys Inc. (21), and Shoppers Drug Mart by Loblaw (in 2014) (55). Metro completed its own drugstore acquisition in 2018, buying Jean Coutu (56) while Sobeys completed its acquisitions of Farm Boy in 2018 (48), and Longos in 2021 (57).

By 2017, five companies (Loblaw, Sobeys, Metro, Walmart, and Giant Tiger) held over 70% of the Canadian grocery market (58). In the same year, there were approximately 7,000 independent grocery and convenience retailers remaining. By 2018, Costco and Walmart

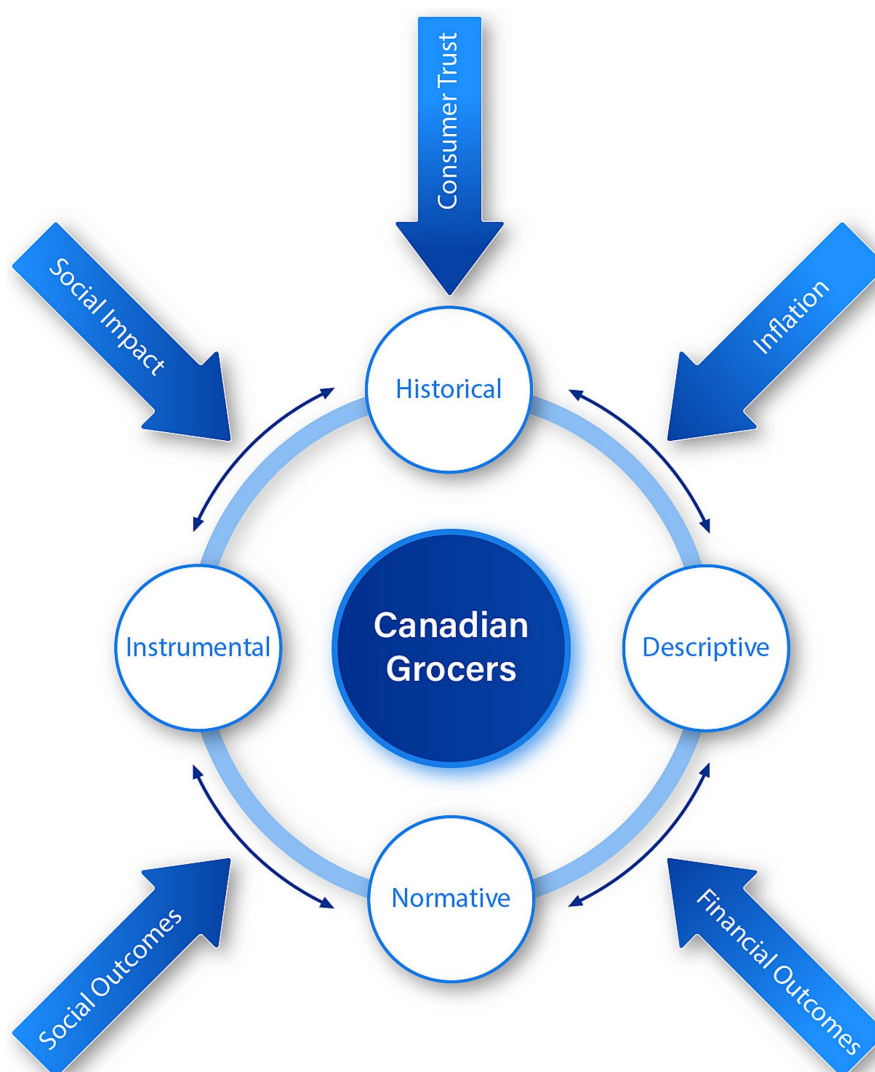


FIGURE 1
Analyzing the moral landscape of Canadian grocers, a conceptual model.

held market shares of 11 and 8%, respectively (59). At this point, the 7,000 independent grocery and convenience stores held approximately 20% of the market share (59).

Pressures leading to consolidation

In examining the factors that have contributed to the present state of the Canadian grocery industry, it may be beneficial to focus on the more recent history, starting in 1998. This marks a significant point in time, as it coincided with the entry of major American firms such as Costco and Walmart into the Canadian market. These market entries can be seen as a defining moment that separates the past from the current state of the Canadian grocery industry. Prior to 1998, market consolidation was primarily driven by the pursuit of greater scale, integration, and product diversity.

Market pressures

“The entry of United States competitors appears to have had a significant impact on market pressures, with Canadian grocers now

focusing on competition with United States entrants. This implies that American firms can leverage their larger scale to pass on price efficiencies to their customers, necessitating an increased scale for Canadian grocers to remain competitive. Regarding the Empire-Oshawa deal, George Fleishmann, then President of the Food and Consumer Product Manufacturers of Canada, was quoted as saying, “The consolidation is necessary as the Canadian industry prepares itself for competition from larger North American discount operations such as Costco and Walmart’s new venture into the grocery business” (60).

Of the Provigo-Loblaw deal, the then commissioner of the Competition Bureau concluded “that increased competition is anticipated within the market from warehouse clubs, such as Costco, or mass merchandisers, such as Wal-Mart” (61). Later mergers do, however, still rely on arguments about promoting price efficiencies through synergies and a need to increase diversity in product offering. For example, Loblaw had the following to say about the acquisition of Shoppers Drug Mart: “It strengthens both companies’ competitiveness

in an evolving retail landscape, creating new growth opportunities for shareholders. It will give consumers more choice, value and convenience” (62).

Regulatory pressures

The regulatory pressures involved in the industry’s dealmaking can be best characterized by a seemingly paradoxical lack of pressure. As previously mentioned, when discussing the Provigo-Loblaw deal, the Commissioner of the Competition Bureau pointed out that increased competition was expected from retail giants like Costco and Walmart. In the case of the Loblaw-Provigo deal, the Competition Bureau mandated that Loblaw divest itself of 18 stores and nine pharmacy operations (63), despite gaining more than 1,200 drug stores across all provinces from the deal (20). In the Sobeys-Oshawa deal the Competition Bureau required Sobeys to divest of five stores and a distribution center, although the company had over 700 stores already at the time (64). The small-scale divestitures mandated by the Competition Bureau underscore the Bureau’s regional approach to competition analysis. This approach seems aimed at preventing specific regions from being devoid of competitive grocery options within predetermined areas. Nevertheless, there appears to be a lack of substantial evidence regarding the analysis of these divestitures’ potential impact on the overall grocery market in Canada.

Comparison to other countries

When examining the history of Canadian grocery retail, it is pertinent to inquire whether Canada exhibits any unique characteristics when compared to its peer nations. The United States stands as a suitable point of comparison both in terms of geography and culture, while the United Kingdom provides a valuable perspective in terms of culture and politics. It is worth noting that the Overton Window in the United Kingdom may be positioned in a manner similar to that of Canada. Turning our attention to the United States, we observe a comparable level of market concentration among the top five grocery retailers. In 2017, these top five retailers collectively held a 66% market share, though it is important to highlight that certain regions exhibited even greater concentration. For instance, in the southern region of Texas, a striking 87% of the market share was controlled by just two companies (58).

In the United Kingdom, there exists a notable level of market concentration among the major industry players, although this concentration is comparatively lower than that observed in Canada and the United States. According to a 2021, MarketLine report focusing on the Food and Grocery Retail industry in the United Kingdom, “The market is primarily controlled by prominent multinational corporations.” The four most significant retailers in this sector—Tesco, Sainsbury’s, Asda, and Morrisons—collectively command more than half of the market share (65). Although these countries exhibit a high degree of concentration among top players, Canada stands out as unique in that its degree of concentration is even higher.

Considering that Canada has reached a juncture where the three largest Canadian public grocery retailers exert significant control over the market, our analysis will concentrate on these three companies. We will present our findings pertaining to Canadian grocers by employing the three facets of the paradox perspective on corporate sustainability, namely the descriptive, instrumental, and normative aspects.

Descriptive

We have looked into media, including coverage on operating segment results, as well as corporate press releases and published interviews that describe and explain the moral landscape of Canadian grocers.

Media

Canadian grocers have garnered significant media attention in recent years due to issues such as bread price-fixing, labor union conflicts, the discontinuation of COVID-19 hero pay, and the emergence of record-high food prices and profits.

The Competition Bureau’s ongoing investigation into alleged price-fixing aimed at artificially inflating bread prices was publicly disclosed in 2017. This disclosure subsequently led to a class-action lawsuit being filed on behalf of Canadian consumers (66). Loblaw Companies Ltd., along with several of its subsidiaries, and George Weston Ltd. were the sole entities offering compensation in the form of \$25 gift cards to customers (66). Other entities mentioned in the lawsuit, such as Metro Inc. and Sobeys Inc., have denied any involvement (66).

Grocery prices and corporate profits have soared over the last year, while grocery store workers continue to battle grocery giants in the quest for fair treatment. A recent example can be seen when more than 500 workers were laid off at a Loblaw distribution center in Calgary in 2022. Many workers are on strike for fair wages with Loblaw only offering a “straight money offer” with no regulations around working conditions (67).

“Hero pay” was a term employed to describe the additional compensation provided to front-line workers, including grocery retail staff, whose efforts enabled Canadians to access essential goods and services during the COVID-19 lockdowns. This pay was introduced in March 2020 by several grocery chains and was discontinued in the first half of June of the same year, sparking controversy (68).

It is not unexpected that grocery retailers are currently under heightened scrutiny due to the growth in both gross and net margins in absolute dollar terms. This scrutiny comes at a time when many Canadian families are grappling with decisions concerning the preservation of discretionary income or even how to provide for their households. In contrast, the concept of shareholder primacy posits that the primary purpose of a corporation is to generate returns for its shareholders, with decision-making oriented toward a singular objective: maximizing shareholder value (69).

In the mainstream media, plenty of attention has been focused on high food prices, which are an important driver of CPI. They also hit lower-income households the hardest. Several industries engage in the sale and production of food: grocery stores, the manufacturers of food and soft drinks, alcohol, tobacco and cannabis, as well as the agriculture industry itself. Three of these four industries have had higher pre-tax profits in 2021 than before the pandemic (70).

Food and beverage stores, such as grocery stores, were the biggest winners in this segment. They made \$3.9 billion more pre-tax profit in 2021 than they did before the pandemic. Grocery stores faced higher input costs, as their cost of goods hit a record high in the third quarter of 2021. But these stores could pass that entire cost increase on to consumers while adding price markups. The industry hit record-high profit margins in the first quarter of 2021, squeezing more profit

out of every dollar that it received in revenue compared to any other time in history (70).

On the other hand, the agriculture sector (i.e., Farmers) saw its profits cut in half in 2021 compared to pre-pandemic times, largely due to the drought in the summer of 2021. All other food industries that are higher up in the supply chain hit new all-time highs in profits and/or profit margins while farmers literally felt the heat (70).

Operating segments

Required reporting for operating segments for public companies is laid out by International Financial Reporting Standard 8 Operating Segments. “Two or more operating segments may be aggregated into a single operating segment if aggregation is consistent with the core principle of this IFRS, the segments have similar economic characteristics, and the segments are similar.” Annual reports for Canadian grocery retailers report all grocery results as one segment on the premise that the nature of the products and services are similar.

The Kroger Co.’s Notice of 2022 Annual Meeting of Shareholders 2022 Proxy Statement and 2021 Annual Report on Form 10-K states: “The Company’s retail operations, which represent 97% of the Company’s consolidated sales, are its only reportable segment” (23).

Metro indicates in their Q3 interim financial report, “We are pleased with the performance of our food and pharmacy businesses in the third quarter, which was achieved in a challenging operating environment with increasing inflationary pressures” (71).

“The thing is, Canada’s major grocers, a group that also includes Metro Inc., have the ability to help lay the charges to rest. They decline to do so, however, using a loophole in accounting standards to obscure the facts about their operations. Their decisions to not publish greater detail on their businesses deprives the investing public of information that allows it to better evaluate the companies’ shares, and the general public of information that might help address the policy question of whether grocers have indeed ‘profited’ from inflation” (72).

Loblaw and its peers are failing at that objective. For the sake of shareholders and Canadians, it is time to get more disclosure about the parts of grocers’ businesses that are driving expanding profit margins (72).

Press releases and published interviews

Reactions from the major players in the grocery industry can be characterized as indignant, citing a lack of understanding of the underpinnings of the business and compliance with requisite accounting regulations.

Asked for additional comment, Loblaw spokesperson Catherine Thomas said: “We’re comfortable with our continuous disclosure. It meets all accounting and legal requirements and provides our investors with an appropriate amount of color on our business.” Metro declined to comment beyond its disclosures, while Empire did not respond to The Globe’s queries (72).

In a letter shared with some of its customers on Monday, Loblaw chairperson and president Galen G. Weston says the

price of an average basket of groceries is up about 10 per cent this year, with such items as apples, soup, and chips up even more. Weston said much of this is “maddeningly” out of the company’s control as food suppliers pass on higher costs to Loblaw (73).

Instrumental

The instrumental aspect looks at short and long-term outcomes. Short term outcomes tend to be less than 1 year and are displayed as aggregated interim data for recent quarterly performance. Long-term outcomes of public market grocers may be measured with financial returns over a period of years.

Interim data

The financial analysis of grocery quarterly earnings for the calendar year 2022 is shared with permission from Dalhousie University’s Agri-food Analytics Lab (3).

We found the best and average gross profit for the most recent 5 years were 25.47 and 24.88% for Empire/Sobeys, 19.99 and 19.82% for Metro, and 31.47 and 30.45% for Loblaw. We compared this historical performance against each company’s most recent two quarters, and our findings are in Table 1 (3).

All large grocers have an increase in gross profit in 2022 relative to their average past performance: Empire/Sobeys earned an excess of \$56 million; Metro earned an excess of \$7 million, and Loblaw earned an excess of \$436 million. We observed Empire/Sobeys’ performance in 2022 was overperforming relative to their best years in Q2 by \$7 million, while their Q3 numbers had them underperforming by \$44 million. For the most recent two quarters of 2022, Empire/Sobeys had a net deficit of \$37 million relative to their best years’ performance (3).

When looking at performance of Metro (49) relative to its best years, we noted they were overperforming in Q1 by \$3 million and underperforming by \$14 million in Q2. For the most recent two quarters of 2022, Metro Inc. had a net deficit of \$11 million relative to their best years’ performance. In Q1 2022, Loblaw outperformed their best years’ performance equivalent to \$68 million; in Q2 2022, they outperformed their best years’ performance by \$112 million. In total, Loblaw’s gross profit thus far in 2022 outperforms its best performance of the past 5 years by \$180 million (3).

Corporate returns

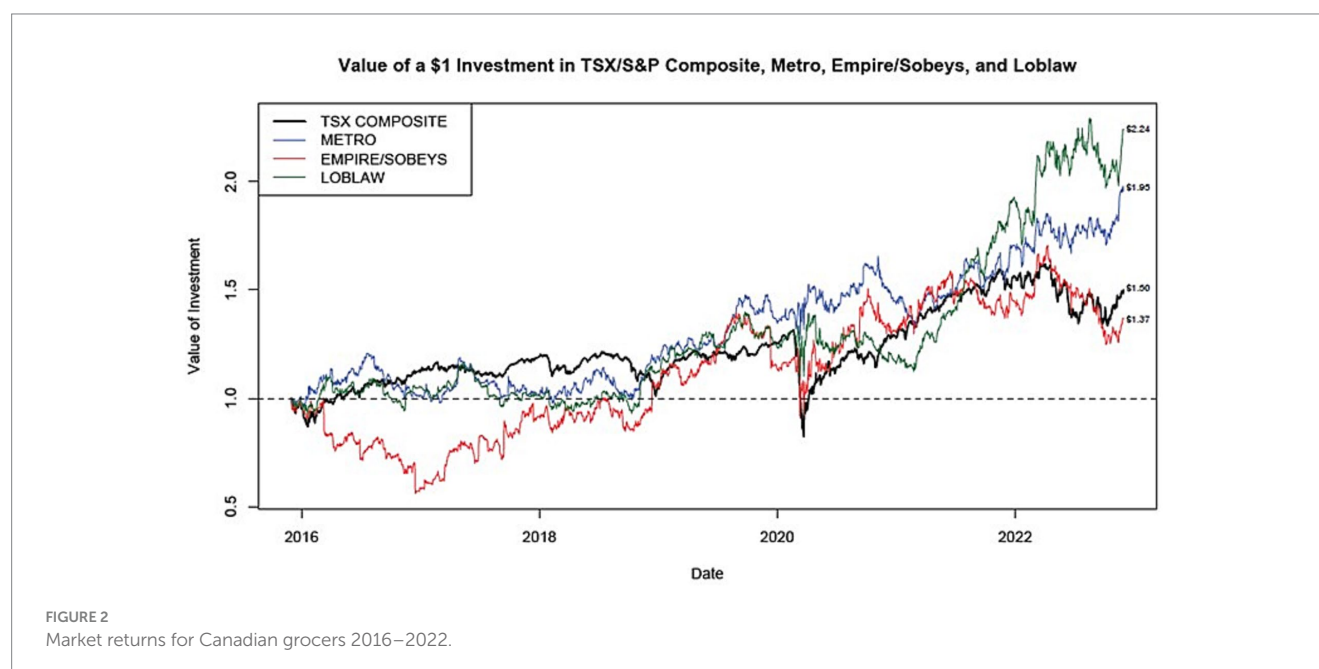
Corporate returns reflect the market’s assessment of the financial strength and viability of a corporation. We have included both the capital gains (i.e., growth in share price) and the total market returns (i.e., capital gains and dividends) to compare the results of each public company grocers’ strategic results.

Capital gains

Capital gains returns reflect the market’s assessment of the strength and viability of a corporation as perceived by current and potential investors. Figure 2 shows the market returns for Canadian grocers from 2016 to 2022.

TABLE 1 Canadian grocer historical performance.

	Empire/Sobeys		Metro		Loblaw	
CAD in Millions	22-Apr	22-Jul	22-Mar	22-Jun	22-Mar	22-Jun
Revenue	\$7,840.8	\$7,937.6	\$4,274.2	\$5,865.5	\$12,262.0	\$12,847.0
Cost of revenue	\$5,836.8	\$5,959.7	\$3,416.8	\$4,706.8	\$8,335.0	\$8,692.0
Gross profit	\$2,004.0	\$1,977.9	\$857.4	\$1,158.7	\$3,927.0	\$4,155.0
Gross profit % – Actual	25.56%	24.92%	20.06%	19.75%	32.03%	32.34%
Gross profit % – 5-year average threshold	24.88%	24.88%	19.82%	19.82%	30.45%	30.45%
Gross profit in excess of 5-year average threshold (%)	0.68%	0.04%	0.24%	−0.07%	1.58%	1.89%
Gross profit in excess of 5-year average threshold (\$)	\$53.2	\$3.0	\$10.3	−\$3.8	\$193.2	\$243.1
Gross profit % – 5-year best threshold	25.47%	25.47%	19.99%	19.99%	31.47%	31.47%
Gross profit in excess of 5-year best threshold (%)	0.09%	−0.55%	0.07%	−0.24%	0.56%	0.87%
Gross profit in excess of 5-year best threshold (\$)	\$6.9	−\$43.8	\$3.0	−\$13.8	\$68.1	\$112.0



For a period of 5 years (December 1, 2017, to November 30, 2022) a \$1 investment in each of the Canadian public grocers grew to \$2.24 (Loblaw), \$1.95 (Metro), and \$1.37 (Empire/Sobeys). Over the same period, \$1 invested in the TSX/S&P Composite would have grown to \$1.50.

Total market

Total market returns reflect the market's assessment of the strength and viability of a corporation as perceived by current and potential investors and the dividends declared and paid by the corporation. [Figure 3](#) shows the total market returns for Canadian grocers 2016–2022.

For a period of 5 years (December 1, 2017, to November 30, 2022) a \$1 investment in each of the Canadian public grocers provided a total return of \$2.52 (Loblaw), \$2.18 (Metro), and \$1.54 (Empire/Sobeys). Over the same period, \$1 invested in the TSX/S&P Composite would have returned \$1.85.

Normative

The normative aspect allows for corporations to be a part of a greater discussion of the role of sustainable business practices. Given the lack of regulation of food prices in the Canadian mixed-market economy, it follows the lack of current normative practices of Canadian grocers.

Competition bureau investigation

On October 24, 2022, Canada's Competition Bureau announced they would be investigating the Canadian food supply chain. Below are the main questions addressed in that press release ([74](#)).

The study will examine three main questions: To what extent are higher grocery prices a result of changing competitive dynamics? What can we learn from steps that other countries have taken to increase competition in the sector? How can governments lower

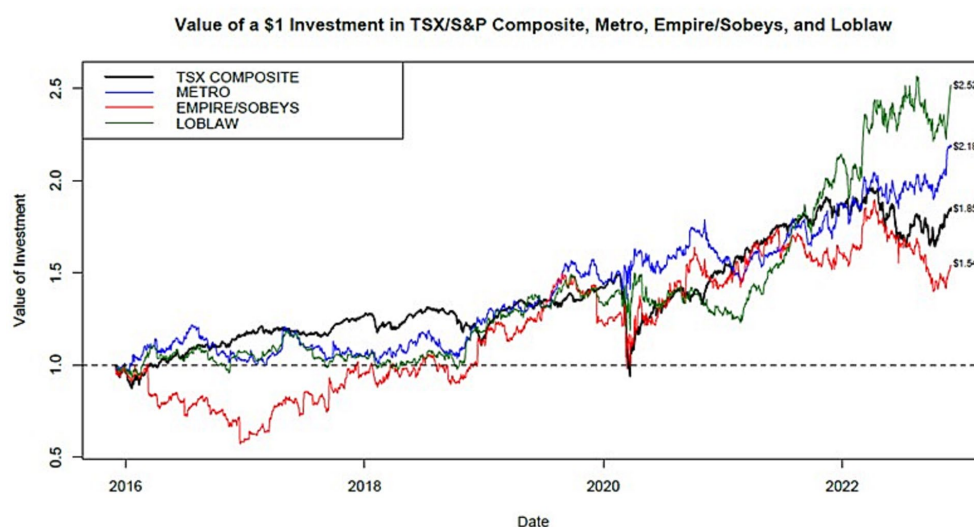


FIGURE 3
Total market returns for Canadian grocers 2016–2022.

barriers to entry and expansion to stimulate competition for consumers?

Discussion

Our findings suggest that record food inflation and a lack of transparency have eroded consumer trust in grocers. At a time of unprecedented inflation, a dearth of regulations, and increased consumer ability to voice concerns, a storm of “Greedflation” anxieties has emerged. A Canadian grocer has been found guilty of price-fixing for bread and may have engaged in tacit collusion to eliminate “hero pay.” Some have even resorted to threatening union lockouts when workers requested improved working conditions. Simultaneously, grocers are enjoying favorable financial and market returns.

Gross profit is the difference between the prices grocers charge (revenues) and the cost of putting items on their shelves (cost of revenues). When discussing “Greedflation,” the concern is that grocers are capitalizing on high inflation to set prices unreasonably high. However, determining what constitutes “excessive” profit is challenging. By examining a company’s gross profit percentage (gross profit divided by sales multiplied by 100), we can establish a relative basis for year-over-year analysis. All three Canadian public grocers are outperforming the average in terms of gross profit, with the largest grocer, Loblaw, achieving its best gross profit performance yet (3).

To address their record-high performance, Loblaw’s earnings press release stated Q2 News Release attributes of Loblaw Reports 2022 Second Quarter Results (75) its increase in sales to an increase in same-store sales for food retail (0.9%) and drug retail (5.6%). This does not necessarily imply that the increase in gross profit can be attributed to the 0.9 and 5.6% respective increases in revenues from food and drug. However, the manner in which the information

is presented may give such an impression. Similarly, when examining Metro’s Q3 financial statements concerning their food and pharmacy businesses, it appears that the retailer also treats these as distinct segments. This raises questions about how grocery retailers interpret what qualifies as a reportable segment. If annual reports provided a more detailed breakdown of results, the public would have a better opportunity to gain a clearer understanding of the underlying dynamics.

Due to current international reporting standards, Loblaw’s is not required to disclose the gross profit for each operating line (e.g., food, drugs, clothing, and beauty). Under international reporting standards, companies may aggregate operating segments with economically similar characteristics when segments are similar in all respects of the nature of, and customers for, their products and services, production, methods of distribution, and nature of the regulatory environment (76). IFRS does not provide a fulsome definition of the term “economic characteristics.” However, they do provide an example within the text of IFRS 8 in section 12 of the standard which reads:

Operating segments often exhibit similar long-term financial performance if they have similar economic characteristics. For example, similar long-term average gross margins for two operating segments would be expected if their economic characteristics were similar.

While this is a useful starting point for understanding what IFRS means when using the term “economic characteristics,” the picture becomes clearer when combined with the core principle of the standard. Section 1 reads:

An entity shall disclose information to enable users of its financial statements to evaluate the nature and financial effects of the business activities in which it engages and the economic environments in which it operates.

These two sections, in combination, allow us to make a reasonable inference about the spirit of the standard. In our view, IFRS' intention is for reporting entities to disclose separate segments that have materially different gross margins because a financial statement user making an investment decision would care about those margins. A conjured example helps illustrate the point: If an investor were trying to decide whether or not to invest in Loblaw but found out that they have a margin of -10% on food, and $+30\%$ on drugstore and clothing, they might believe it prudent to use their input as a shareholder to encourage the company to divest of its food business, and simply remain a drugstore and clothing store.

Under the current situation, it is impossible for users of financial statements to make this determination, which we would say is material to the investment decision making process. As recently as July 2022 Loblaw had told the public that their increased profits were due to their drugstore products, and not grocery products (77). This could be due to changes in volume of sales but also different gross margins being provided by these assorted products. Hence, we would say that they are not reporting within the spirit of the standard that is IFRS 8.

Canadian public grocery retailers are subject to quarterly reviews and annual audits as a requirement of their public company status in Canada. Consequently, management assertions and judgments regarding operating segments have undergone evaluation by third-party auditors and have been found to be free of material misstatements. This implies that although it may not be immediately evident that the grocery industry shares similarities in terms of its nature, customer base, or production processes with other sectors such as pharmaceuticals, clothing, or beauty, both grocery store management and auditors have established a sufficient basis to conclude that they are, in fact, similar (to a reasonable extent).

Nevertheless, it is important to note that any changes in food-related regulations in Canada could potentially impact the interpretation of the last part of IFRS 8.12, specifically the section addressing the 'nature of the regulatory environment'.

Food is a fundamental human necessity, akin to housing, heating, and transportation. Unlike food prices, which are subject to market forces, housing, utilities, and specific segments of the transportation sector in Canada are influenced by regulatory measures aimed at ensuring equitable pricing for Canadians. In cases where there is a dearth of competition, such as in certain provincial utilities, these industries are subject to comprehensive government oversight. Nearly three-quarters of Canadians contend that they face challenges in satisfying their essential needs (78). Simultaneously, Canadian grocers continue to experience consistently robust economic performance, showing no signs of decline. This prompts consideration for enhanced government oversight regarding the pricing of food products for Canadian consumers.

Government regulation of food retailers could play a pivotal role in ensuring Canadians can adequately provide for their families while fostering increased transparency in the reporting of results within Canadian grocery store operating segments. Should regulations be introduced for grocery financial reporting, it is plausible that grocer management and third-party auditors may face heightened challenges

when attempting to consolidate sales and gross margins from distinct categories such as food, drugs, clothing, and beauty.

Recent press releases from grocers have seen the release of select pieces of information, often used to justify their heightened gross profit margins, with claims that food sales have remained "relatively flat," while gross profit margins on pharmaceutical drugs have witnessed an increase. Remarkably, the public response does not seem to express outrage toward grocers making increased profits on pharmaceuticals. This observation suggests that if grocers indeed experience heightened gross profits in other lines of business, increased transparency in reporting could serve to earn consumers' trust, consequently reducing the scrutiny placed on corporate profits. In other words, the perception of corporate profiteering in the food sector may be ameliorated through enhanced transparency in operating segments, which distinctly delineate gross profits from food and other product lines.

Our research findings strongly indicate that record food inflation and the absence of transparency have adversely impacted consumer trust in grocers. However, the extent to which this has influenced consumer purchasing behavior remains unclear. Future research endeavors could delve into the intricate relationship between consumer trust and food inflation, shedding light on the potential consequences for consumer behavior in the grocery retail sector.

Conclusion

Forty-year record-high inflation and unprecedented food prices are currently impacting Canadians. Consequently, consumers are calling for increased government oversight. The implementation of a mandatory grocer code of conduct and enhanced transparency in financial reporting operating segments would empower stakeholders to assess the sources of grocer profits independently. Through these measures, grocers may begin to rebuild the trust that has been eroded among consumers. Paradoxically, when social needs are no longer perceived as neglected or exploited, corporate profits may indeed continue to rise, but this time with reduced scrutiny and social unrest.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, upon reasonable request.

Author contributions

ST: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. SC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – review & editing, Writing – original draft. TC: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. BC:

Data curation, Formal analysis, Investigation, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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An insight into market and non-market alternative food networks in Czechia during Covid-19 and beyond

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Introduction: The Covid-19 pandemic affected food systems in many countries and emphasized a lot of already existing social, economic and environmental agri-food problems. Alternative food networks (AFNs), praised for their ability to improve the food systems, were under stress, however, at the same time, the changed conditions may have opened new possibilities. In this paper we address the importance of AFNs during the pandemic and investigate how households have changed their participation in AFNs. Our research is novel by simultaneously focusing on both market and non-market AFNs which are often studied separately.

Methods: A representative questionnaire study of Czech households was carried out in Autumn 2021 to provide a case study of food and consumption behavior of the European country after several waves of Covid-19.

Results and discussion: Based on the responses of 515 participants, the results show that 68% of Czech households participate in some form of AFNs, be it shopping or food self-provisioning, i.e., non-market food procurement in the form of gardening. Focusing on the market AFNs, farmers' markets and farm gate sales are the most popular. Covid-19 and 2021 emerging economic pressures led to a decrease of consumption of organic food (22% of respondents) as well as fresh fruit and vegetables in general (10% of respondents) and a noticeable occurrence of food insecurity (18% of households). Based on these findings, the paper discusses the ability of AFNs to support food and nutritional resilience. Problems which may endanger market-oriented AFNs are discussed as well.

Conclusion: By addressing both market and non-market AFNs, the paper brings new knowledge into the food environment and agri-food policies research.

KEYWORDS

Agri-food value chains, alternative food networks, COVID-19, food self-provisioning, food behavior, resilience

1 Introduction

In light of the Covid-19 pandemic and subsequent socio-economic changes, weaknesses and problems were exposed uncompromisingly in the entire food chain. It disclosed high dependence on just-in-time supplies leading to short-run disruptions

during unexpected events (1). Furthermore, on the supply side—producers, suppliers, and retailers across the chain—all had to deal with issues such as employee cuts, stricter hygiene rules or other government anti-pandemic measures (2, 3). Many of them had to face a loss of market demand caused for instance by closures of restaurants, bans on farmers' markets and festivals, etc. Applied measures also affected the consumer side, such as various mobility restrictions or lockdowns affecting their demand, frequency, and amount of shopping (4, 5). Moreover, on the consumer side, the effects of the pandemic are addressed in a number of studies that highlight concerns about adopting unhealthy eating habits combined with psychological problems (6, 7). In addition, the problem of unavailability of quality and fresh food due to financial problems may have deepened (6, 8), as evidenced by the growing increase in the interest in services of food banks (9, 10). To sum up, these disruptions in food supply during the pandemic and associated socio-economic changes have tested the resilience and adaptability of each segment within the food supply chain (4, 11).

In response to emerging issues of the globalized agri-food system during the pandemic, international communities called for actions to prevent disruption of food supply chains. The Food and Agricultural Organization of the United Nations (FAO) points out that mainly small and medium agribusiness enterprises are at risk due to pandemic (12). Among others, FAO calls for building local food production to build more resilient local food systems (13) and a set of public financial support and policy responses (14, 15). Furthermore, re-localization trends are receiving more attention and researchers are calling attention to the need for transformation – the development of environmentally friendly practices and the promotion of short food supply chains (16–18). Some authors see the pandemic as an opportunity for a more dynamic process of converging consumers with food production (1, 19), and communities are seen as the most important drivers of change (16, 20, 21).

Given the aforementioned themes and research results, this paper contributes to the discussion about the trends observed among consumers, which can support or, on the contrary, threaten the transformation of the agri-food system with regard to local food orientation and sustainability. Following this, it is crucial to capture information about consumer practices in relation to alternative food networks (AFNs). In this study, we perceive the AFNs concept as a framework referring to connecting producers with consumers as well as to sustainable practices within food production and consumption (22). The value-added of our research is the inclusion of AFNs operating outside the market—namely food self-provisioning (further as FSP), considering it an important and widespread element of a non-commercial way of obtaining food, which can play an important role in social resilience (23), namely in rural areas (24). Both AFNs and FSP have strong potential to contribute to the sustainable, even post-growth, transformation of food systems and can be seen as already existing alternatives to the dominant globalized food chains (25).

This study is inspired by the research focused on the impact of the pandemic on the whole agri-food system, including wider food policy implications for Czechia as a mid-sized post-socialist country with specific agricultural and food systems situated in Central Europe. In this paper, food consumption is placed in the context of the whole agri-food system and the findings presented

here are key to the discussion of sustainability and resilience as well as the changes that can enhance or threaten these aspects in food production and consumption. While a number of articles were based on data collected during the first wave of the pandemic in Spring 2020 [e.g., Millard et al. (5)], our study focuses on food-related behavior and local food supply using the data collected in the Autumn 2021. This enables us to gain a better overview about aspects which either became the “new normal” or returned back to the previous state after the first Covid-19 shock in 2020. The main research questions are:

To what extent do consumers use alternative food networks to acquire food?

How have food acquisition and eating habits changed in the context of the pandemic?

With regard to the above questions, our objective is to discuss some key challenges and implications for food policy.

2 Evidence of selected changes and trends in response to the Covid-19 pandemic

A significant number of studies have been published on changes in consumer behavior and lifestyle as a consequence of the pandemic, however, the prevalent proportion of studies reflects only the first wave of the pandemic (Spring 2020). The results vary, depending on the different geographical contexts as well as the research design. Also, due to time the limitations of the research (the first shocking experience with the pandemic situation), results should be treated cautiously. Within the evidence in Western countries, a number of studies agree on observations of certain trends of resilience concerns relating to population health, food safety and food justice [e.g., (5, 7, 26, 27)]. Regarding the effects of the pandemic on households, it is not surprising that one of the most decisive factors detected within the research which influenced consumer behavior and eating habits was income change (5, 6, 26). Especially the study by Millard et al. (5) revealed that households, fragile even before the pandemic, experienced a loss of income during Covid-19 which then made their situation worse. Other research has shown that the impacts vary across population groups with different socio-economic characteristics, but families with children are understandably identified as vulnerable groups (6, 26).

Psychological factors influencing food behavior should not be neglected. The need for stockpiling can be explained by a decrease in food shopping frequency as a result of restricted mobility and fear of infection [this trend is confirmed by Vidal-Mones et al. (28), Millard et al. (5) or Babbitt et al. (29)]. In terms of the amount of food consumed, many people reported an increase in food intake, however, the problem lies in the change in diet. Consumers have experienced a decline in dietary quality—less fruit, vegetables, meat and fish were eaten, in contrast to more consumed cheap foods or those with a long shelf life—that is, industrially processed products (5–7). The need to address food availability in the future is also evidenced by the increase in the workload of food

banks. From the donors' point of view, Oncini (30) clearly reports a significant increase in the volume of donated food, confirmed by 76% of organizations in the sample. The aforementioned observation led to discussions on how to address the growing problems of obesity and diseases associated with poor eating habits such as diabetes as well as food insecurity (7, 10, 31).

3 Specific situation of the agri-food system and AFNs in Czechia

The agri-food system in Czechia differs from that of Western Europe, which is the consequence of decades of the communist regime in the 20th century and the post-socialist transition. The socialist model of industrial agriculture was based on destruction of private farming and an emphasis on high concentration of large-scale socialist cooperatives. After the change of the regime in 1989, economic transformation and subsequent privatization took place in Czechia (32, 33).

3.1 Perspective of Czech consumers

Related to retail landscapes and consumer behavior, the very dynamic processes were shaped by internationalization trends and the adoption of Western models and patterns of shopping behavior (34) leading to the enormous spread of foreign retail companies in the form of large-scale retail formats (such as hypermarkets, supermarkets, discount stores and shopping malls) and causing a radical transformation of retail networks in post-socialist cities (35). Therefore, transnational corporations have gained dominance, and partially replaced traditional smaller retail facilities (36, 37).

However, the quantitative boom was followed by a sobering of consumers caused by scandals of retail chains and information circulating in the media that supermarkets in Czechia sell food of lower quality than in neighboring countries (37). Thus, consumers choices started to be oriented not only to common and cheap products but also took into account aspects of the locality (36) and the "quality and safety" of food (38), which is a process referred to as a quality turn in the context of Western countries (39). Relatively new data on the growing interest in food quality is provided by Severová et al. (40), who state that the number of such quality-aware consumers increased from 35 to 40% within 5 years. Together with new trends of food behavior, the evolution of AFNs on the market has been underway. However, given the fact of adopting (or importing) ideas and elements of market-oriented AFNs developed in Western countries to the context of Central and Eastern European countries, researchers point out some specific local characteristics and the different evolution of AFNs due to their different settings (32, 41). Regarding AFNs coming to the Czech market during the last decades, farmers' markets began to develop around 2010, followed by other forms of AFNs such as community-supported agriculture (CSA) or box schemes. To compare—in neighboring Germany, these forms of direct sale have been operating for more than half a century (42). However, it should be noted that some forms of markets and farmers' shops (or collective farms' shops during communism) have been part of the Czech AFNs for many decades, especially in rural areas.

The consumers' side is monitored mainly via public opinion surveys. Comprehensive results are presented by the research of Spilková (36) comprising 3,168 respondents. The most popular forms were the farmers' markets (38% of the respondents do sometimes shop there) and direct shopping at the farm gate (23% of respondents). Farm shops were used by almost 18% of respondents and box schemes were utilized by 5% of respondents. Similar results can be seen in a recent public opinion poll regarding consumers' preference to local food (43), which showed that more than two fifths of respondents (out of a total of 1,549) at least sometimes buy local food. Among the forms of AFNs we monitored in our research too, the most popular was direct purchase from local producers (48%), farmers' markets (47%) and local vegetable markets (44%). Pick your own food was mentioned by 31% of respondents, online option by 16% of respondents and as the latest option CSA was selected by 5% of respondents. Taking into account socio-demographic characteristics, according to Spilková (36), AFNs are in general favored by women and highly educated people in managerial positions or entrepreneurs.

Specifically, farmers' markets experienced a big boom in the capital Prague, connected to local political support in several city quarters. Fendrychová and Jehlička (41) pointed out some disproportion between expectations, promotion on the one side and capacity of suppliers on the other side, especially at the beginning of the boom of farmers' markets which Prague experienced in the early 2010. In less than 24 months, 41 farmers' markets were established in and around the city, but as time went by, the numbers decreased and the market stabilized. Currently, around 140 farmers' markets are evidenced in Czechia according to publicly available databases [e.g., (44)]. The least numerous form of sales—CSA—began to develop in Czechia in a similar period as farmers' markets, but they are not expanding as dynamically (the same applies to box schemes). According to continual international monitoring of CSA, around 80 groups containing 5,000 people are active in Czechia, cooperating with 30 farms in 2020 (45).

Regarding other forms of AFNs, media report the increasing trend of interest in pick-your-own. Especially after the experience with the Covid-19 pandemic, initiatives were created to map the locations of farms offering this service. Furthermore, more emphasis is placed on the promotion by social networks and online sales. Unfortunately, there is no database available which would provide a comprehensive overview of AFNs activities. Partial data can be collected through different (mutually uncoordinated) initiatives that carry out surveys, however, available databases often lack updates.

3.2 Position of small-scale food farmers in Czechia

With regard to producers, the involvement of farms in AFNs is quite low. It may be a consequence of the large-scale agribusiness model, which remained dominant even after the post-socialist economic transition, although with private owners. Thus, the current agri-food production and consequent food processing part of the food systems is distorted due to the high concentration of big agribusiness enterprises that control the food market supply and prices. According to the statistics, nearly 30,000 farms operate in Czechia, while 60% of

agricultural land is held by only 1,740 (6%) of farms which are larger than 500 ha. An overwhelming 86% of agricultural land is managed by only 5,000 (17%) of farms which are larger than 100 ha (46). Czechia is the country with the highest average area per agricultural holding: 133 ha in 2013, compared to an EU average 16 ha (47).

The main reason of such a low proportion of small and medium farms is the fact that the landowners, who received the land back in the 1990s restitutions, often sold or rented the agricultural land to a local agro-enterprise (often a previously former large socialist cooperative farm). The descendants of former farmers usually found it impossible to get back into farming after nearly 40 years of disruption. Thus, a significant number of the former socialist cooperatives at the time remained and were merely transformed into different legal forms of entrepreneurship (48). These large enterprises work better on the basis of large-scale agriculture linked to the food (and other) industry and the number of small and medium farms is relatively low which together leads to low involvement of farms in AFNs.

This could be illustrated by a case study of the Moravian-Silesian region by Hruška et al. (32). Analyzing publicly available (but not exhaustive) databases on the internet, they revealed that the proportion of farms integrated into AFNs was 1.4% of all farms in the region (5% of the total number of organic farms) in 2018. The low AFNs representation within the market is also indicated by the report of the Ministry of Agriculture, which states that the share of organic food (which is an integral part of the AFNs concept) in the total consumption of food and beverages in 2020 reached 1.8% (49).

3.3 Non-market aspects of AFNs based on food self-provisioning

Additionally, to market-oriented AFNs, informal food networks and non-commercial food activities are considered to be part of AFNs too by some authors. As argued by Daněk et al. (50), although AFNs is a concept dominantly developed in Western countries, many similarities can be observed with FSP, including the motivation of participants and material, social and environmental outcomes. FSP has strong roots in Europe, in the countryside as an integral part of life and in the cities especially since the 19th century as a way of ensuring food security for the growing working class (51). Informal food networks flourished during World War I as well as World War II. During the second half of the 20th century FSP was more common in countries of Central and Eastern Europe, yet it remained popular in some of the West European countries too (52) and experienced a boom in the Covid-19 pandemic (53). FSP is still a vivid phenomenon and hobby activity accompanied by a rich combination of sharing, exchanging and gifting food products (54–56). Surplus food from own production is sometimes also unofficially sold from so-called “the yard” – for example honey or eggs. These activities show a significant level of the persisting practice among the population despite the dominance of either centrally planned socialist or free-market capitalist economy.

While the concept of AFNs is associated with criticism that it appeals to consumers in cities with higher incomes and higher education (57), according to research to date, a diverse range of social groups participate in FSP. Although FSP was associated with the narrative of the so-called coping strategy, i.e., activities carried out due to the need to obtain enough food (unavailable due to lack of finance

or lack of food on the market), this approach has been successfully overcome in research (50). Research of gardeners’ motivations supports this interpretative change, proving that having fresh and healthy food as well as a leisure activity are the main motivations for gardening, though financial motives cannot be fully dismissed (24, 58, 59).

The proportion of people participating in FSP in Czechia is more or less stable in time and oscillates between 40 and 45 percent of the population in the last two decades (60) with a recent increasing trend (58). Research shows that FSP is widespread among the whole Czech society, though it is more often practiced in rural areas (55), mostly due to higher availability of land for gardening in family houses with gardens. Fruit, vegetables, or potatoes are often grown but domestic animals are kept too to a lesser extent (24). Despite the focus of our study on Czechia, it should be noted that FSP is typical for other Global North countries too [e.g., (52, 61)]. Apart from the food growing itself, positive outcomes for well-being and life satisfaction are attributed to it as well (62).

4 Methods

The data were collected by the professional market research agency Median in October 2021. Participation in the questionnaire survey was voluntary and anonymous. A sample of 515 respondents representative of the adult Czech population was selected by quota sampling following these criteria: sex, age, education, municipality size and region. Data collection combined Computer Assisted Web Interview (online survey, CAWI) and Computer Assisted Telephone Interview (CATI) in order to include the part of the population reluctant to use the internet. Out of a total 515 respondents, 449 were CAWI and 66 CATI which reflects the share of the offline population according to the data and experience of the market research agency. See Table 1 for a complete overview of the sociodemographic characteristics of the respondents. The survey sample reflects the adult population with a very low deviation of less than 1% in most of the sociodemographic characteristics (see Table 1 in Supplementary material for a comparison of the sample and the Czech adult population according to the sampling quotas). There is only one exception in which our sample differs more from the overall Czech population–housing type. There is a higher share of households living in family houses in the sample than in reality which might potentially slightly increase the share of FSP in the results as this is commonly practiced by those with household gardens (see below). However, this characteristic was not a sampling quota. We keep this and other limitations in mind while discussing the results and summarize them in the 5.5 Limitations section.

The questionnaire was a follow-up to the international research initiative “Our relation to food during Covid-19 pandemic,”¹ which reflected the first wave of the pandemic in Spring 2020 in several European countries [see (5) for details]. The original set of questions focused on changes in food behavior and the perceived risk associated with Covid-19 was complemented with questions focusing on food resilience, AFNs and food growing in our 2021 survey. It reflects food

¹ <https://www.food-covid-19.org/>

TABLE 1 Sociodemographic characteristics.

	Respondents
Sex	
Male	48.9%
Female	51.1%
Age groups	
18–34	23.3%
35–49	32.0%
50–64	24.1%
65+	20.6%
Education	
Grammar	10.9%
Lower middle	34.6%
Upper middle	36.7%
University	17.9%
Economic activity	
Employee	52.0%
Self-entrepreneur	6.0%
Student	6.2%
Retired	27.8%
Unemployed	3.1%
Other (parental leave, homemaker, etc.)	4.9%
Household net income	
< 416 EUR	1.7%
417–833 EUR	17.5%
834–1,250 EUR	15.7%
1,251–1,666 EUR	16.7%
1,667–2,083 EUR	19.2%
2,083–3,125 EUR	15.5%
3,126+ EUR	6.1%
Do not know/do not want to say	7.5%
Children under 20 years in household (% yes)	37.5%
Municipality size	
< 1,000	16.9%
1,000–4,999	21.7%
5,000–19,999	19.8%
20,000–99,999	20.6%
100,000+	21.0%
House type	
Family house	46.2%
Apartment	51.8%
Other	1.9%

N = 515. Question Household net income originally had 18 categories, in this table it is summarized into 7 categories. It was recoded into quintiles (see Results and discussion for details), Municipality size was recoded to urban/rural binary variable (5,000 inhabitants as threshold) and respondents answering “Other” on the question on House type were omitted from the logistic regressions. Exchange rate 1 Euro = 24 CZK was used for the income conversion.

behavior after the experience of three pandemic waves with peaks in October 2020, January, and March 2021 and before the start of the fourth wave peaking at the end of November 2021. Since the start of

the pandemic in March 2020, the Czech government declared a state of emergency several times, associated with specific anti-epidemic measures impacting the food sector and households (including the

repeated ban on farmers' markets, strict hygiene regulations, mandatory vaccinations for entering restaurants, etc.).² Given the timing of our survey, it detects the main trends in light of adopting anti-pandemic measures and changing socio-economic conditions in Czechia, mainly starting with the increase of food prices.

Given the main themes of the research initiative mentioned above, the whole questionnaire consisted of sections focusing on the following thematic areas:

- food shopping (particular types of shops and direct purchase from producers), changes in shopping frequency during the pandemic,
- food behavior (consumption of specific types of food, changes during the pandemic, reduced consumption for financial reasons, food anxiety, food donations),
- food self-provisioning (access to a garden, attitude to food self-provisioning, assessment of the importance of food self-provisioning in total consumption).

This paper presents results of the analyses of answers to the selected topics: types of shops used with a special focus on the types of AFNs, changes in food-related behavior (food security, food consumption, food shopping) and food growing. The particular wording of all analyzed questions as well as frequencies of the answers in per cent can be found in [Supplementary material](#).

Statistical analysis of the data was processed with IBM SPSS 28 software. Methods include descriptive statistics, Pearson correlation, crosstabulations with Chi-square and logistic regression. If not stated otherwise, the statistical significance mentioned in the text is on the level of 5%.

5 Results and discussion

The following sections respond to the research questions and the results are discussed with the findings of other foreign and domestic research as well as public opinion polls. Section 5.1. and 5.2 respond to the first research question: *To what extent do consumers use alternative food networks to acquire food?* Section 5.3 analyses in more depth the participation of households in AFNs with respect to sociodemographic indicators. Additionally, an analysis is conducted on the spatial perspective that differentiates households in rural and urban areas. Section 5.4 focuses on answering the second research question: *How have food acquisition and eating habits changed in the context of the pandemic?*

5.1 Food purchase

In this section, the situation in the food market is examined in more detail: where people buy food and how many of them use market-oriented AFNs. Two separate questions focused on fresh fruit and vegetables and other fresh food (dairy and bakery products, meat, pastries, etc.) are combined in [Table 2](#).

The results show that supermarkets and hypermarkets are the most common place for food shopping, confirmed by almost 92% of respondents. It is likely that the process of consolidating the dominant position of large retail chains, lasting several decades, is continuing.

According to Rättinger et al. (38), in 1997 a quarter of Czech households shopped in large retail chains and by 2013 it was 86%. Therefore, it seems realistic that this number continued to grow. Small, specialized shops such as greengrocers, butchers or bakeries still maintain their position with over half of the population visiting them. Three of the eight types of shops were classified as AFNs: organic/local/healthy food shops, markets (including traditional markets where food is sold by resellers and the origin of the food is not addressed as well as new farmers' markets) and direct purchase from producers.³ As [Table 2](#) shows, markets and direct purchase from producers are more popular than specialized shops with organic, local and healthy food. When summarized, the share of respondents who buy either fruit and vegetables or fresh food (or both) in any of the three types of alternative food network shopping places is 37.5%. This group is hereafter referred to as AFNs shoppers.

When focusing on the direct purchase from producers only, (19.6% of the sample, see [Table 2](#)), the vast majority of this group (72%) buy food directly at the farm gate sale or in the farm shop. Farm gate sale seems to be organizationally simple and financially advantageous for both clients and sellers, moreover, the opportunity to visit farmers and see with their own eyes where their food comes from is very attractive for customers. This may be related to consumers' need to obtain food from a trusted source, because as the study by Carfora and Catellani (63) states, trust is one of the three decisive factors (along with availability and health) motivating consumers to buy local food.

Regarding direct sales, it is also necessary to mention the so-called hybridization of AFNs, which in the post-socialist environment manifests itself in the involvement of large farms in direct sales to consumers [described in the aforementioned study by Hruška et al. (32) or Fendrychová and Jehlička (41)]. Here it is necessary to say that farm shops and farm gate sales were already used in state enterprises during socialism, so consumers are used to it. However, there is a certain dilemma, how to identify this model from the point of view of AFNs—there is a rapprochement between the consumer and the producer, but the way of managing the business can be entirely conventional. In our research, direct purchase at farm gate or in farm shops is considered to be participation in an AFNs, regardless of the

² The first state of emergency (12 March to 17 May 2020) was accompanied with very strict measures. Only shops with basic assortment, including food, were opened and canteens remained open to serve takeaway. The second state of emergency (5 October 2020 to 11 April 2021) applied similar measures, but not as strict. Restaurants, cafes and canteens had limited opening hours (except for children, vaccination certificate needed) and shops remained more or less open. In the discussion section we use some of these events to contextualize the results of our survey.

³ It is worth noting that the "cooperatives" are not considered to be part of AFNs in this study despite the fact that there is a network of stores based on the philosophy of cooperatives. However, this type of shop offers most of the goods identical to conventional retail and does not seek to change the usual market-oriented relationship between producers and consumers.

TABLE 2 Where food is being purchased.

Type of shop	YES, any fresh food	Yes, detailed			No
		Both	Fruit and vegetables only	Other fresh food only	
Super/hypermarkets	91.5%	80%	6.8%	4.7%	8.5%
Small shops	56.9%	30.5%	5.8%	20.6%	43.1%
Cooperative shops	6.4%	2.1%	0.2%	4.1%	93.6%
Organic/local/healthy food shops	8%	3.5%	2.9%	1.6%	92%
Farmers' and other markets	21.6%	8.3%	10.5%	2.7%	78.4%
Local growers and producers	19.6%	6.8%	9.7%	3.1%	80.4%
Home delivery (online or phone order)	7.8%	5%	1.7%	1%	92.2%
Other	7.0%	1.6%	4.9%	0.6%	93%

Each type of shop was questioned separately (yes/no) sum of these two answers is 100%. $N = 515$.

size or type of farm. We find the direct contact between producers and consumer most important from the perspective of this study.

Other popular ways of purchase are based on online shopping with a different way of delivery: via social networks and flexible delivery (17%), online order with pick up at the farm (12%), regular box scheme with delivery to specific place of distribution (11%) and regular box scheme with delivery to home (10%). We assume that online marketing will become more important, and it could be a suitable strategy for farms in the future to maintain their market position and reach new customers, which is already observed in the aforementioned research [see (64, 65)]. Another form of purchase was self-picking on the field (10%) which has become heavily promoted in advertisements in the last 3 years and is most often used when selling strawberries and apples. Also, 9% of respondents referred to the open answer “other forms” mostly without clarification. Finally, minimal interest was found in relation to CSA (1%),⁴ which corresponds to the above-mentioned literature demonstrating the lagging behind of CSA compared to other forms of AFNs (43, 45). It seems like Czech consumers have not become accustomed to closer and more binding cooperation with the producer to a large extent. Despite low distribution, the local and solidarity-based partnerships show a high level of allegiance even in times of crisis. CSA and similar models reported high resilience: 90% of them confirmed in a global survey (among 40 countries including Czechia) that they did not experience any interruption of deliveries at all. On the contrary, they experienced a slight increase in the interest of newcomers in joining them (66).

Considering the situation of the local food market from the point of view of consumers, our results and other studies indicate that there is a group of consumers interested in local food, but the local food market is not sufficiently developed. Moreover, farmers or producers oriented to direct sales find it difficult to compete with commodities from the conventional market controlled by large business entities. The problem with the local food market and barriers hindering its

development is illustrated by the opinion of the Czech public reported in a survey by Hanzlová (43), in which 61% of respondents perceive a lack of local producers and farmers in the vicinity of their residence. Furthermore, 91% of the respondents think that support for local food is insufficient (at the level of the EU, Czechia, regions and microregions). In addition, they perceive cheap food from foreign sources and large agricultural enterprises as the main problem obstructing the production and sale of local food.

5.2 Food self-provisioning

Another area of interest are AFNs operating outside the market environment, i.e., in our case food self-provisioning. As mentioned above, FSP can include keeping domestic animals. In this text we often use the term “grow food” for the sake of simplicity which can include keeping animals too (see [Supplementary material](#) for exact wording of the questions). A major FSP-related question asked respondents to choose the answer best matching the relation of their household to own food production (see [Figure 1](#)). The overall share of respondents who grow fruit and vegetables (or keep domestic animals for food) is 51.5%. This number is accompanied by another 11.7% of respondents who consider growing food in future. While some of the respondents who chose option “Other” also mentioned occasional food growing, we consider them as non-growing to be rather conservative and respect their perspective.⁵ Taking into account the results in other studies, the increasing interest in growing own food is confirmed also by Millard et al. (5), who recorded this trend in both rural and urban areas. As for studies beyond the European context, in Canada, Mullins et al. (67) records an increase in new people interested in their own food production, especially in urban areas. Another study describes a growing interest in food self-provisioning in New York, with respondents' clear intention to strengthen control over food availability (68). Further, Egerer et al. (69) dealt with FSP during the pandemic and emphasized the importance of this activity in relation to financial savings. In addition,

⁴ It should be stressed again that the shares of different types of direct purchases are shown in per cent of one fifth of the population which participates in this type of shopping. This means that, apart from direct purchase at a farm or farm's shop, these types of shopping are marginal among the general population.

⁵ Potential inclusion of this small subgroup into food growers would not change meaning of any of the analysis and conclusions in this study.

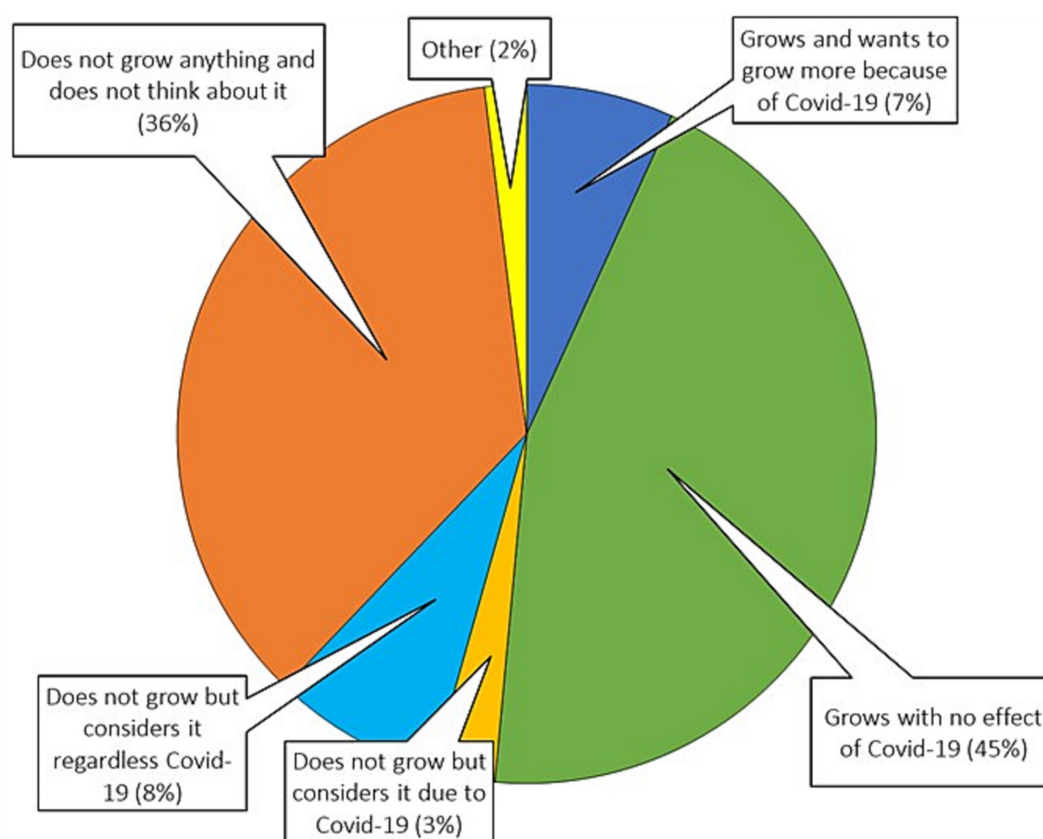


FIGURE 1
Households' approach to FSP. Sum may not be 100% due to rounding. $N = 515$.

they revealed a link between the growing interest in gardening and concerns about in-store shopping and access to fresh food.

To evaluate the importance of FSP in terms of amount of produced food and to assess the level of food resilience, respondents were asked to indicate how important is their own production compared to food shopping (in terms of fruits, vegetables, potatoes, eggs, etc.) (Table 3). Growing fruit and vegetables is a supplementary source for 42.6% of food growers and for another 40.8%, it is only a negligible seasonal source. For nearly one-fifth (17%) of food growing households, it is a major source of food comparable to shopping (answers majority + essential). We are aware of the fact that it is a subjective estimate of the respondents, yet it is supported by previous research, both in local case studies as well as in large surveys using different assessment methods, including questionnaires, interviews or food logs (23, 24, 70). FSP can be seen as a significant source of fresh and healthy food. When recalculating the households for whom FSP is a major or essential source of food as a share of total population, it is 8.8% of households. Such a number is slightly higher than the share of households shopping via home delivery or visiting specialized shops with organic, local and healthy food.

Respondents were also asked whether their households have access to a place where fruit or vegetables can be grown. Various possibilities were offered in the questionnaire (answers yes/no). Most of the respondents who grow food have access to a private garden (69.8%). The following accessible places where food could be grown include weekend house garden (18.9%), balcony or indoor gardening

(17%), gardens of relatives (13.6%) and allotment gardens (7.5%). Community gardens are rather rare (0.8%). Similarly as in the case of food shopping, respondents often have access to more than one type of garden, and therefore the sum in per cent exceeds 100%. This confirms previous results showing that home gardens are the most important place for food growing (58), yet they tend to be less researched than more politicized gardens often being in public spaces, like allotments and community gardens.

Considering the evidence of growing interest in FSP, a question of availability of land for growing, especially in cities, emerges. The preservation and development of allotment and community gardens enabling food growing to those inhabitants who do not have access to their own garden should be a part of food policies. Municipalities ought to allow long term lease contracts of public land to enable the cultivation of fresh food and enhance local food production (13, 71, 72). In this regard, there is a significant gap in the strategies of Czech municipalities. Although the Gardening Act No. 221/2021 Coll. approved in Czechia in 2021 recognizes gardening as a publicly beneficial activity, there are many misconceptions in the practice of creating strategic documents. As stated by Pixová and Plank (73), who focused on the research of relevant documents in the Czech metropolises Prague and Brno, city leaders tend to understand the environmental, recreational and aesthetic benefits of gardens. However, they neglect the real function of food production for consumption which can be significant for some households and is relatively high in general (23). While community gardens are coming

TABLE 3 The importance of own food in total food consumption.

Respondent's answer	%
Covers majority of food consumption	6.8%
Essential source, comparable with shopping	9.8%
Supplementary source	42.6%
Negligible seasonal source	40.8%
No importance	0.4%

N = 265 (food growing households only).

to the fore as a trend from the Western countries, they are still a minor phenomenon in Czechia, as our research shows. They are often seen as something trendy even by local politicians and planners who paradoxically oppose traditional forms of FSP, like allotment gardens, which are well established and productive (70). Often, allotment gardens in the cities are facing extinction to make way for development projects. An epistemic rehabilitation⁶ of traditional FSP types, like allotment gardens, in the minds of politicians and planners is needed to enable a more critical attitude toward many housing and commercial real estate projects. So far, the arguments to keep the allotments and other places for potential food growing undeveloped are raised mostly by local residents, academics or NGOs which is not sufficient.

5.3 Households participating in AFNs

Our findings show that AFNs shopping is practiced by 37.5%, while food growing by 51.5% households. Both of these can be obviously done by the same households. Table 4 shows how these activities are related to each other. Two thirds of households participate in any kind of AFNs, be it market or non-market oriented. Pearson correlation of binary variables AFNs shopping and food growing does not reveal any significant relationship but a slight positive trend suggesting that participation in one activity is linked to the other ($r = 0.086$, $p = 0.52$). Based on this finding, we can argue that AFNs shopping and food growing are not mutually exclusive (i.e., participating in one activity would limit participating in the other) and tends to be mutually supporting, though we have to be careful with this conclusion. This is a different finding than, for example, results of a US study by Schupp and

TABLE 4 AFNs shopping and food growing in per cent.

		AFNs shopping	
		Yes	No
Food growing	Yes	21.4%	30.1%
	No	16.1%	32.4%

N = 515.

⁶ For more details about the relationship of FSP in Eastern and Western Europe, different interpretations of very similar activities and the importance of knowledge production see, e.g., Jehlička et al. (74), Daněk et al. (50) or Jehlička (75).

Sharp (61) who found a significant positive relationship between participation in local food systems shopping and FSP.

The effect of sociodemographic characteristics was tested by logistic regressions with binary dependent categories AFNs shopping and food growing and independent sociodemographic as binary or categorical variables. Some characteristics were used in the form shown in the Tab. 1 (sex, age group, education, children under 20 in the household). Income was transformed into quintiles for the purpose of the analysis. This was done by dividing the mean of the income category in the questionnaire by the weighted number of household members⁷ and then transforming into quintiles. Narrowly understood economic activity was limited to binary categories of active (employee, self-employed) and inactive (student, retired, unemployed, other). Similarly, place of living was also reduced to binary category rural/urban with municipality size of 5,000 inhabitants as the distinction between rural and urban.⁸ In the case of house type, category “Other” with a small number of cases was omitted from the logistic regression.

Regarding AFNs shopping, place of living was the only one significant independent variable ($\beta = 1.809$, $p = 0.011$) showing higher probability of AFNs shopping in urban areas. However, the overall explanatory power of the regression was weak (Nagelkerke $R^2 = 0.040$, $N = 467$ due to some missing values). The regression explained more variability in the case of food growing (Nagelkerke $R^2 = 0.315$, $N = 467$) with two independent variables being significant: house type ($\beta = 0.153$, $p < 0.001$)⁹ and place of living ($\beta = 0.559$, $p = 0.018$) showing that households living in family houses as well as in rural areas have greater chance to grow food.

When assessing the weak effect of sociodemographic factors, an issue of discrepancy between individual characteristics and questions aimed at behavior of the whole household may arise. This aspect may have some influence, yet the households tend to be socially coherent units with similar characteristics of its members. In the case of FSP, previous research supports our findings about the low effect of sociodemographic [e.g., (55, 59)]. Thus, based on our results, we argue that both AFNs shopping and food growing are socially inclusive practices widespread among various social groups. Given the fact that place of living is the only variable affecting both AFNs shopping and food growing, we show the comparison of them for urban and rural areas separately in Figure 2. The group of households participating in both market AFNs and FSP is similar in urban as well as rural areas, while shopping at AFNs only or no participation in AFNs is more common in urban areas. On the contrary, sole food growing is much more frequent in rural areas.

The different distribution of AFNs shopping and FSP in urban and rural areas might have consequences for farmers. As Hruška et al. (32) argue, widespread food growing in rural areas may be seen as a competition for fruit and vegetable-oriented farmers because people

⁷ Simplified weights inspired by OECD equivalence scale (76) were used: first household member = 1, every other member = 0.7.

⁸ We are aware of the complexity of the whole rural–urban categorization and other possible thresholds (e.g., 2,000 or 3,000).

⁹ Given the effect of living in a family house on the participation in FSP and the overrepresentation of such types of houses in our sample, the exact share of 51.5% of food growing households might be slightly higher than in reality. However, it is in agreement with a previous recent study by Hanzlová (58).

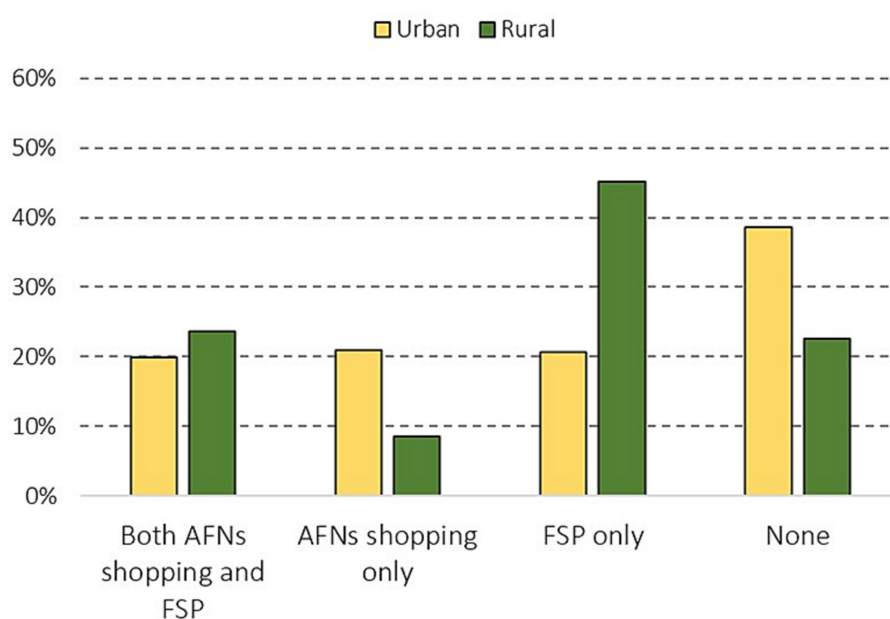


FIGURE 2

AFNs shopping and food growing in urban and rural areas. Overall significance tested by Chi-square ($\chi^2=46.616$, d.f.=3, $p<0.001$). Differences between urban and rural areas are statistically significant for all categories (Adj. Res. ≥ 1.96 ; $p<0.01$) except participating in both AFNs shopping and FSP.

living in rural areas are used to growing their own food. Our research supports this statement by showing a large group of food growers who do not shop in AFNs, yet it does not mean that the food growing households participate less in AFNs shopping in rural areas ($r=0.068$; $p=0.338$). The link between food growing and AFNs shopping is stronger in towns and cities than in rural areas as the correlation shows significant results ($r=0.141$; $p=0.012$). Despite the share of households not participating in any of the two types of food gathering is higher in urban areas (38.9 to 22.6%), the overall number of households being involved in AFNs shopping is higher (40.8 to 32.1%). Given the generally high level of urbanization of the country, developing AFNs in towns and cities, or attracting urban dwellers to direct purchase at the farm gate, seem to be a vital business strategy for farmers.

The foregoing findings addressing the potential barriers to the development of the local food market are reinforced by findings from a study by Carfora and Catellani (63), who identified availability as the most important element in local food decision-making. This is valid both in terms of seasonality and of space, as the possibilities differ in urban and rural settings. While consumers in the countryside are closer to individual farms, the offer in the city is generally more varied, as products concentrate at distinct sales points. They are, however, generally more expensive.

5.4 Changes during Covid-19

In the following section three aspects of changes during the Covid-19 pandemic are analyzed: financial aspects, changes in food shopping and food consumption. In each case, the effect of participation in AFNs shopping as well as FSP is analyzed. This allows us to answer the second and third research questions (changes in

food-related habits and its policy implications). Full descriptive statistics of the categories of answers are shown in Tables 5, 6, including the significance of Chi-square analysis of the relationship between changes during Covid-19 and the separately tested effect of participation in AFNs shopping and FSP. Changes during Covid-19 were originally measured on Likert-like scales with 3- or 5-categories and were recoded to binary or 3-categories variables for the analysis (see Supplementary material).

5.4.1 Financial aspects of Covid-19 and its impact on food security

Within our sample, 28.9% of respondents confirmed a decrease in household income during Covid-19, while only 11.7% reported an increase (see Table 5). Contrary to this, 13.8% confirmed a reduced amount of money spent on food but increased expenses were confirmed by 37.7% of respondents. To clarify the situation in terms of food security, we asked for concerns about food shortages, which were confirmed by more than a third of respondents (4.9% often and 30.9% sometimes). The real experience with a lack of food applied to a smaller, yet relatively high, share of respondents: 2.7% reported a lack of food in the household often and another 15% sometimes. We were also interested in the group of respondents who confirmed the use of food donations—the use of resources such as food banks, charities or restaurants/apps was confirmed by 3.9–8.6% of respondents, of whom only a minority stated that it was an important source of food and the rest of them identified these sources as a supplementary/negligible source. Food donations from relatives or friends was more common with 35.1%, respectively 21.6% of respondents receiving some food. Similarly as in the case of food from institutions, it was only a supplementary or negligible source of food for the vast majority of the respondents.

TABLE 5 Income change, food anxiety and shortages, food donations.

Income change					
	<i>Decrease</i>	<i>No change</i>	<i>Increase</i>	Effect of AFNs shopping	Effect of FSP
Income during Covid-19	28.9%	59.4%	11.7%	$p = 0.586$	$p = 0.286$

N = 515.

Food anxiety and shortages					
	<i>Often</i>	<i>Sometimes</i>	<i>Never</i>	Effect of AFNs shopping	Effect of FSP
Food anxiety	4.9%	30.9%	64.3%	$p = 0.474$	$p = 0.121$
Food shortages	2.7%	15%	82.3%	$p = 0.990$	$p = 0.047$

N = 515. Respondents from food growing households report more often that they have never experienced a lack of food (Adj. Res. = 2.3; $\chi^2 = 6.126$; d.f. = 2). Bold text highlights $p < 0.05$.

Food donations					
	<i>Important source</i>	<i>supplementary/negligible source</i>	<i>No use</i>	Effect of AFNs shopping	Effect of FSP
Food banks	1.6%	3.1%	95.3%	$p = 0.289$	$p = 0.317$
Charities	0.8%	3.1%	96.1%	$p = 0.098$	$p = 0.293$
Restaurants/Apps	1.4%	7.2%	91.5%	$p = 0.886$	$p = 0.266$
Relatives	3.5%	31.7%	64.9%	$p = 0.572$	$p = 0.112$
Friends	0.8%	20.8%	78.4%	$p = 0.046$	$p = 0.088$

N = 515. Original five categories were recoded into three: Important includes covering most consumption and essential source; middle category merging supplementary and negligible source and no use remaining the same. Only one case shows statistical significance ($\chi^2 = 6.148$; d.f. = 2). AFN shoppers reporting food donations from friends being supplemental/negligible source more often (Adj. Res. = 2.4) and no use less often (Adj. Res. = -2.3). Bold text highlights $p < 0.05$.

It follows on from previous research showing that food is often donated by friends or relatives who grow the food themselves (55, 58). There were only two cases that showed a significant effect of AFNs shopping or FSP. First, food growing households experienced food shortages less often than non-growing households. Second, AFNs shopping households used food donations from friends more often as supplementary/negligible source of food than other households. The significance was right below the 5% threshold, yet it suggests some positive effect from being involved in AFNs.

5.4.2 Changes in food shopping and consumption

The time of the pandemic brought new influences on consumer behavior; therefore, respondents were asked to evaluate changes (decrease or increase) in the frequency of visits to selected shopping places compared to the time before the pandemic. The results do not indicate significant changes and these results might indicate the good accessibility of conventional shops in general (as Table 6 shows). However, Lichter and Malý (35) found that government restrictions had different impacts on (not only) food purchase accessibility in cities, depending on the various types of urban structure that implies diverse forms and assortment of retail units. Thus, the authors argue that more comprehensive retail planning that reflects the potential local impacts of global crises is essential to ensure greater spatial equity in access to basic daily commodities. Regarding AFNs, a change was noted for farmers' markets, where 6.2% of respondents indicated

a decrease in the frequency of visits while 4.5% reported increase. It is difficult to assess the causes and the validity, because in Czechia farmers' markets were banned in certain phases of the lockdown in 2020 and 2021 as part of anti-pandemic measures. With regard to the wider European context (including data from Czechia), other signs of the unfavorable situation of AFNs are reported by Millard et al. (5), showing a significant decline in purchases in AFNs shops (e.g., farmers' markets, street markets, cooperatively owned or solidarity shops, specialist organic food outlets and buying food directly from the producers) during the pandemic. Although, the authors admit this may be affected by the period when data were collected too because the harvest period had not yet fully begun (Spring 2020). The only one type of shop in our 2021 research whose use was affected by AFNs shopping or FSP were small shops. Households which visit AFNs shops as well as those which grow food reported increased frequency of visiting small shops.

Regarding changes in food consumption, 17.1% of respondents reduced their overall food intake, which may not be the result of financial problems, but if we take into account that 21.9% of respondents confirmed a reduction in the amount of food of organic quality, we can conclude that a certain group tried to reduce expenses in the area of food. Financial uncertainty on the part of consumers leads to a reduction in the purchase of organic food, which is traditionally more expensive than those from conventional production (8). Therefore, the observed reduction in the consumption of products of organic origin can be considered a threat in terms of the development

TABLE 6 Changes in food shopping and food behavior.

Changes in food shopping					
	<i>Decrease</i>	<i>No change</i>	<i>Increase</i>	Effect of AFNs shopping	Effect of FSP
Supermarkets	22.7%	62.1%	6.6%	$p = 0.302$	$p = 0.895$
Small shops	8.7%	35.9%	12.2%	$p = 0.005$	$p < 0.001$
Cooperatives	0.8%	3.9%	1.7%	$p = 0.797$	$p = 0.696$
Organic	1.9%	4.5%	1.6%	–	$p = 0.850$
Markets	6.2%	10.9%	4.5%	–	$p = 0.536$
Local producers	2.7%	11.7%	5.2%	–	$p = 0.131$
Online	0.8%	2.9%	4.1%	$p = 0.953$	$p = 0.074$

N ranges from 33 (Cooperatives) to 471 (Supermarkets) due to the fact that only respondents shopping in a particular type of shop answered this question. However, the percentage relates to all respondents ($N = 515$) to reflect how many households do not use the particular type of shop (see also [Supplementary material](#)). The results are calculated as mean of original 5-item scale of fresh fruit and vegetables and other fresh food which was then recoded into three categories. There are positive effects of both AFN shopping ($\chi^2 = 10.411$; d.f. = 2) as well as FSP ($\chi^2 = 16.752$; d.f. = 2) on using small shops. In both cases, households participating in AFN shopping or FSP more often reported an increase of shopping frequency (Adj. Res. = 2.1 in both cases) and less often reported its decrease (Adj. Res. = –2.8 and –3.9). Bold text highlights $p < 0.05$.

Changes compared to before Covid-19					
	<i>Decrease</i>	<i>No change</i>	<i>Increase</i>	Effect of AFNs shopping	Effect of FSP
Amount of food consumed	17.1%	72.6%	10.3%	$p = 0.967$	$p = 0.465$
Amount of food from local growers and producers	16.1%	73.4%	10.5%	$p < 0.001$	$p = 0.003$
Amount of organic food	21.9%	69.5%	8.5%	$p = 0.098$	$p = 0.653$

$N = 515$. Original five categories were recoded into three. There are positive effects of both AFN shopping ($\chi^2 = 19.374$; d.f. = 2) as well as FSP ($\chi^2 = 11.336$; d.f. = 2) on the amount of food from local producers and growers. Note: Respondents participating in AFN shopping increased the amount of food from local producers more often (Adj. Res. = 4.4) and less often reported no change of the amount (Adj. Res. = 2.2). This is expectable, yet we have included all respondents into the analysis, as AFN non-shoppers may buy some local food in other types of shops. Food growing respondents less often reported a decreased amount of food from local producers (Adj. Res. = –3.3). Bold text highlights $p < 0.05$.

Food consumption decrease					
	<i>Yes</i>	<i>No</i>		Effect of AFNs shopping	Effect of FSP
Fresh fruit and veg	9.5%	90.5%		$p = 1.000$	$p = 0.016$
Fresh meat	10.1%	89.9%		$p = 0.763$	$p = 0.028$
Fresh fish	16.5%	83.5%		$p = 0.714$	$p = 0.043$
Bread and bakery	2.7%	97.3%		$p = 0.781$	$p = 0.105$
Milk and milk products	4.5%	95.5%		$p = 0.830$	$p = 0.053$

Note: $N = 515$. Regardless of how often they consume the particular type of food. There is a positive effect of FSP on consumption of several types of food: food growing households report a decrease of consumption of fresh fruit and vegetables (Adj. Res. = –2.5; $\chi^2 = 6.091$; d.f. = 1), fresh meat (Adj. Res. = –2.3; $\chi^2 = 5.153$; d.f. = 1), fresh fish (Adj. Res. = –2.1; $\chi^2 = 4.307$; d.f. = 1) less often. The same non-significant trend applies to milk consumption. Bold text highlights $p < 0.05$.

Frequency of food consumption					
	<i>Less than once a week</i>	<i>1–3 days a week</i>	<i>4 days a week or more</i>	Effect of AFNs shopping	Effect of FSP
Fresh fruit and veg	4.5%	33.4%	62.1%	$p = 0.164$	$p = 0.008$

Note: $N = 515$. Regardless of how often they consume fresh fruit and vegetables. There is a positive effect of FSP on the frequency of consumption of fresh fruit and vegetables ($\chi^2 = 9.540$; d.f. = 2). Respondents from food growing households eat this type of food more often 4 days a week or more (Adj. Res. = 3.0) and less often 1–3 days a week (Adj. Res. = –2.3). Bold text highlights $p < 0.05$.

of the diet's quality and the sustainability of the agri-food system. The reduced interest in organic food is confirmed, for example, by Millard et al. (5), where a decrease of up to 10% is recorded, especially in households with income loss. However, this trend, in particular, will vary between social groups, as suggested by a study by Profeta et al. (6), who state that changes in both directions—decrease and increase—are mutually compensating, so there is no radical change.

In addition, 16.1% of all respondents reported a reduced amount of food produced by local producers or growers. Shopping in AFNs as well as participation in FSP had some effect. Those shopping in AFNs have increased amount of local products purchased more often and food growers reported at least a limited decrease. Thus, consumers involved in at least some form of AFNs (even if it is a form outside the market) seem to be more loyal to the local products [cf. (77)].

With respect to the consumption of specific types of food, consumption was reduced in case of fresh fish (16.5% of respondents), fresh meat (10.1%) and fresh fruit and vegetables (9.5%), while consumption of milk and dairy products (4.5%) as well as bread and bakery (2.7%) were barely affected. Consumption of fresh fruits and vegetables appears to be a striking issue with regard to health and nutrition. Among our respondents, only 35.1% confirmed that they consume these foods daily, while 27% do 4–6 times a week, 23.9% only 2–3 times a week and the remaining 14% once a week or less. At the same time, the World Health Organization recommends the consumption of 400 g of fresh fruit and vegetables per day. The media also draw attention to this problem in Czechia [see, e.g., (46, 78)]. Therefore, more attention should be turned to ensuring food and nutrition security, with a focus on vulnerable groups of inhabitants, such as low-income families, children, elderly, etc. (4, 16). It is worth noting that food growing is associated with a higher frequency of consumption of fresh fruit and vegetables as well as a less frequent drop in the consumption of fresh meat, fresh fish and already mentioned fresh fruit and vegetables. Our results cannot prove causality, however, they suggest that there is a link between FSP and healthy food as well as FSP and stability of diet though it can be indirect.

5.5 Limitation

Nevertheless, our study has several limitations: despite reflecting a representative proportion of the Czech population, the sample size of 515 respondents was not so robust. Thus, the results need to be treated with caution when generalizing. At the same time, we allow for possible distortion due to the prevailing online survey compared to the telephone one. Generalisability of the effect of sociodemographics is limited due to the fact that individual respondents were surveyed but both shopping and food growing are often activities of more household members. Furthermore, the study is limited in time and it would be advisable to repeat it for a more accurate identification of trends. The exact share of food growing households might be slightly affected by the overrepresentation of respondents living in family houses in our sample (yet this could at least be partly balanced by not considering “Other” respondents from Figure 1 as food growers). Finally, the questionnaire asked for frequency of shopping or fruit and vegetables eating but not for the exact amount.

6 Conclusion

Based on our main findings, large retail is the dominant source of fresh food for Czech households. Supermarkets, hypermarkets and discounts are visited by the vast majority of the population. AFNs are also widespread with two-thirds of respondents' households being involved in some form of them, be it market or non-commercial activity (shopping and food growing). These two activities tend to reinforce each other and show a high level of resilience with only small deviations in times of crisis. The results suggest that households have various ways how to get fresh food which is a positive aspect supporting food resilience. When differentiating between market and non-market AFNs, food growing is more widespread than shopping (51.5% compared to 37.5% of respondents) which reflects the traditionally strong position of FSP as

well as specifics of the agri-food system. Given the similar findings of previous research, we conclude that market-oriented AFNs are still underdeveloped in Czechia with cheap food imports and the strong position of large agricultural entities being a barrier to its development. The findings related to FSP, including food sharing, the amount of self-produced food and another 11% of respondents who consider growing in future, make it an important activity which should not be neglected in the sustainability and food policies.

The effect of the Covid-19 pandemic was manifested mainly by the financial problems and to a lesser extent (but visible) by the decrease in food consumption, quality food orientation and AFNs' participation. This shows that in times of trouble, the need to cut expenditures can indirectly affect farmers and food producers selling through AFNs. A striking finding is the low frequency of fresh fruit and vegetables consumption. Despite the drop due to Covid-19 being evident but not crucial, general consumption was quite low before the pandemic and could be expected to lower even more because of rising food prices since October 2021 when the data were collected.

The above-mentioned aspects relate to the resilience of households and food systems as well as nutritional and therefore also health issues. This paper contributes to the current debates with a case study of a Central and Eastern European country, particularly with the novel approach linking together market and non-market AFNs, additionally putting them into the context of the pandemic and potentially also post-pandemic changes.

Based on our study, we suggest several implication and summarizing recommendation for a complex food policy: 1/ An urgent need for policy support of local agri-food value chains is needed, especially via empowerment of small and medium farms to strengthen the abilities of actors of local or regional agri-food supply chains to respond more appropriately to adverse events and to keep these locally oriented systems more resilient. Inspiration is offered at the global level. FAO (13) recognizes the importance of local food systems for ensuring local food accessibility and perceives local food production as a key measure to mitigate the negative impacts of crises. FAO recommends promoting local food production and short supply chains and a higher degree of local or regional self-sufficiency. The argument for integrated food policies with a wider range of stakeholders participating in their design and evaluation and with more balanced power relations is supported by De Schutter (79) as well. It requires a transition from understanding food as a commodity to a common good, including the roles of farmers as stewards of the agricultural landscape and a close community (79, 80). At the state level, logistics and distribution issues should be addressed to encourage the availability of local food (63).

On a regional scale, we point out that a great challenge for local or regional food policies lies in a systematic development of urban and peri-urban agriculture that contributes to regionally based resilience of agri-food territorial systems. Municipalities and regional authorities need to find feasible ways how to preserve agricultural land around cities via spatial planning and various sets of policy instruments, including support of public procurement to enable local food production and consumption (especially fresh fruit and vegetables) based on short distances and tight bonds between producers and urban consumers (5, 81, 82).

2/ Food policies to support sustainable food consumption should widen the perspective of citizens as consumers as well as producers.

Findings from our study show the insufficient consumption of fresh fruits and vegetables on a daily basis to be alarming. According to our results, the consumption of these foods has fallen even further during the pandemic, and considering the extremely quickly rising prices since the questionnaire survey, there is no prospect of improvement. Therefore, more attention should be paid to ensuring food and nutrition security, with a focus on vulnerable groups of inhabitants, such as low income families, children, elderly, etc. (4, 16, 63). It is necessary to make sustainable and healthy diets more affordable and accessible via a mix of policy measures, including educational programs and the presentation of good practices to improve food literacy (83). Furthermore, policymakers can increase consumer trust in local foods by raising the understanding of the health advantages and environmental sustainability.

Our results confirmed that food self-provisioning is an important part of the food system as a source of quality food. Especially in urban areas, the preservation and development of allotment and community gardens enabling food growing for those inhabitants who do not have access to their own garden should be part of food policies ensuring quality food and nutrition security. Municipalities ought to allow long term lease contracts of public land to enable the cultivation of fresh food and enhance local food production (13, 71, 72). In Czechia, support of gardening by municipalities and the Ministry of Agriculture is explicitly designated in Gardening Act No. 221/2021 Coll. and should serve as a practical tool.

Considering upcoming research agenda, our findings could be addressed by future work which can build on this paper and previous studies of AFNs and FSP in various regions of the world. Particularly, the households' response to the increasing food prices and the role of AFNs and FSP and combining of food from various sources should be studied to understand food resilience on the household level. On the higher level of regional food systems, a specific focus on different forms of AFNs and their popularity should be taken to account too, similarly like in the case of FSP, identify those more popular and take the long-term experience or local conditions into account by both sellers and authorities setting the policy frameworks.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ZS: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review

& editing. JV: Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing. BD: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2024.1327308/full#supplementary-material>

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Food systems under shock: the evolution of food security status of Karantina residents after the Beirut explosion

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Robust food systems are crucial for ensuring access to affordable and nutritious food, particularly in times of crisis. Economic instability, currency devaluation, and political turmoil can disrupt food systems, leading to higher food prices, compromised nutrition, and increased vulnerability. Lebanon is a stark example of this, where a catastrophic explosion in Beirut's Port in 2020 worsened an existing economic and humanitarian crisis. The depreciation of the Lebanese currency led to soaring food prices, impacting people's ability to buy food, and pushing many into poverty, illustrating the significant impact of the state food systems during crises (FAO, 2021). In times of crisis, a simplified food system, relying on emergency food aid supplies, replaces conventional food system, as food aid and cash transfers become the primary source upon which the affected population depends to ensure their food security and meet their essential needs. In this article we report on research conducted between 2020 and 2022 focusing on the impacts of the Beirut explosion on food security status of the permanent residents the Karantina neighborhood—the closest residential area to the Beirut port. We surveyed 100 households chosen at random, examining shifts in food security and nutrition at three intervals: 6 months prior to the explosion, 6 months following it, and 2 years after the event. The findings revealed a sharp decline in food security and diet quality among residents in the two-year period following the explosion. The proportion of food-secure households fell from 71% to 2%, while those with acceptable food consumption decreased from 96% to 30%. Additionally, income and debt situations worsened significantly. Almost 95% of residents resorted to crisis coping strategies, such as using savings, borrowing money for food, selling furniture, withdrawing children from school, and reducing education and health expenses, rendering them highly vulnerable. Food and cash assistance were provided to all households for 6 months to one-year post-explosion, resulting in improved food security and consumption after 6 months. However, these gains diminished 2 years later, once the assistance ended, revealing a lack of resilience in the food system. In conclusion, soon after the assistance stopped, the prolonged deterioration of Lebanon's economic situation, compounded by multiple crises, pushed these households further into poverty, exacerbating food insecurity. This research underscores the critical importance of sustained support and comprehensive economic reforms to rebuild food systems and promote nutrition resilience in crisis-affected regions.

KEYWORDS

food (in)security, Beirut blast, food systems, simplified emergency food system, humanitarian assistance, Lebanon

Introduction

On 4th August 2020, a massive explosion occurred at the Port of Beirut, causing extensive destruction in the Lebanese capital, resulting in over 200 fatalities and more than 5,000 injuries (ACTED, 2020). This devastating event led to the obliteration and impairment of over 40,000 structures within a 10-km radius of the port area, encompassing both residential and commercial buildings (Beirut Urban Lab, 2021).

At the time of the blast, Lebanon had already confronted a series of crises, commencing with an economic downturn in 2019 that has continued to deteriorate. The World Food Programme reported that food inflation rates in Lebanon surged by 245% between October 2019 and June 2020, as a result of the compounding impact of the financial crisis and the advent of the COVID-19 pandemic (UNICEF, 2021). Since 80% of the food available in Lebanon's market is imported, the drastic depreciation of the Lebanese currency and the restrictions imposed on food trade during COVID-19 rendered food less available, more expensive, and sometimes even unaffordability (FAO, 2009). In 2020, both food and commodity prices experienced further substantial increases, stemming from the devaluation of the Lebanese currency, which had a direct detrimental effect on the purchasing capacity and food access of households (Kharroubi et al., 2021). By 2021, 1 year after the catastrophic port explosion, the economic crisis's reverberations persisted and intensified due to the absence of urgently needed economic reforms and a lack of accountability and governance. The economic crisis has led to the currency depreciation, high inflation, and increasing food and non-food prices, making it increasingly challenging for households to access and afford an adequate and nutritious diet, resulting in a growing number of Lebanese and refugee families falling deeper into poverty, with millions of people requiring humanitarian aid (World Food Programme, 2021a; Integrated Food Security Phase Classification, 2022).

Adding to the adversity, the COVID-19 pandemic exacerbated the circumstances. Successive lockdown measures resulted in income losses and reduced purchasing power, business shutdowns, and an economic downturn (Béné, 2020). Thus, resulting in the most severe and protracted economic crisis, ranked among the world's top three most severe crises (Kharroubi et al., 2021). By the end of 2021, food insecurity among the population rose to 46% (World Food Programme, 2022).

The Karantina neighborhood was identified as one of the most severely affected areas by the explosion due to its proximity to the port, and consequently, it received a significant portion of the humanitarian aid (Beirut Urban Lab, 2021). This research seeks to ascertain whether the humanitarian aid which largely consisted of cash assistance, extended to the permanent residents of Karantina, exerted enduring and sustainable effects on their food security status and enhance the resilience of the food system. Resilience is the ability of the food system to bounce back after shocks, transcending the immediate recovery phase, in terms of both quantity and quality of

their dietary intake. Therefore, in this research, we hypothesize that cash assistance, when given in conjunction with in-kind food assistance, can be used to catalyze sources of income, and therefore rebuild livelihoods.

Complex food system, and simplified emergency food system

Food security is a fundamental concept that underscores the well-being of individuals and communities. It is articulated as follows: "Food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2009). This definition encapsulates the multi-dimensional nature of food security, emphasizing not just the quantity of food available but also the quality, safety, and equitable access to it. In the broader context of global challenges, achieving food security is a paramount goal, and it relies heavily on the functioning and resilience of food systems, which must adapt to the changing needs and demands of a population (Fanzo, 2023).

Food systems comprise the entirety of individuals, institutions, environments, and activities involved in the production, processing, distribution, marketing, sale, preparation, and consumption of food (Fanzo et al., 2020). Food systems involve food production, considering economic, social, and environmental dimensions. As food systems evolve and adapt, they directly influence the availability, accessibility, and quality of food for people and communities on a global scale (FAO, 2018). Hence, ensuring the resilience and sustainability of food systems as a fundamental component of achieving and upholding food security for all (FAO, 2018; Fanzo, 2023). Resilience and sustainability are characteristics that are bolstered by the complexity of food systems: the higher the diversity of actors, institutions, and activities, the more likely the system will be able to absorb shocks and bounce back to its initial state (FAO, 2021).

Food systems are not immune to crises, and they often face significant challenges that can have far-reaching impacts on food security (FAO, 2018). These crises can manifest in various forms, such as natural disasters, economic shocks, conflicts, and health emergencies. Natural disasters like droughts, floods, or extreme weather events can disrupt agricultural production, leading to food shortages and price spikes. Economic shocks, such as inflation or recession, can affect people's purchasing power and ability to access affordable, nutritious food (Rother et al., 2022). Conflict and political instability can disrupt food supply chains and displace communities, leading to food insecurity among vulnerable populations. Health emergencies, like pandemics, can disrupt food distribution, labor availability, and consumer behavior, further straining food systems (FAO, 2021).

In times of crisis and in the context of humanitarian aid, the functioning of the food system is intentionally simplified to efficiently meet urgent needs. Effective responses and strategies are crucial to mitigate the impacts of these crises on food security. We call this a Simplified Emergency Food System (SEFS) which primarily constitutes emergency food aid, social safety nets, infrastructure repair, and policies aimed at stabilizing prices and ensuring equitable food access (FAO, 2021). Simplified Emergency Food System (SEFS) often play a crucial role in the efficient delivery of food aid. This system is designed to streamline processes, reduce complexity, and ensure that aid reaches those in need as swiftly as possible. SEFS may involve providing readily consumable and non-perishable food items which require minimal preparation and can be distributed without the need for complex cooking facilities or storage (Barrett, 2006).

By focusing on simplicity, food aid organizations can maximize the reach of their assistance, even in challenging conditions (FAO, 2021). SEFS is valuable in emergency situations, such as natural disasters or conflicts, where immediate relief is essential. Additionally, SEFS reduce the burden on the affected populations, who may lack the resources or facilities to engage in elaborate food preparation during a crisis (Barrett, 2006).

Humanitarian assistance post-conflict and crises plays a crucial role in addressing immediate needs, providing essential resources like food, cash, water, health services, and shelter. This aid not only responds to urgent humanitarian requirements but also facilitates community empowerment, allowing for self-reliance, the restoration of essential services, and the revival of economic activities (Martin Belmonte et al., 2021). In times of crisis, the purchasing power of vulnerable, low-income populations significantly affects their food security, leading to prolonged recovery periods due to factors such as the loss of breadwinners and habitat, as well as the elimination of income sources (Deraniyagala, 2016). Therefore, cash assistance plays a pivotal role in times of crisis by fostering resilience within communities and individuals. In the face of emergencies such as natural disasters, pandemics, or economic downturns, providing direct financial support empowers people to navigate challenges and rebuild their lives with dignity (Fadlallah, 2022).

While a simplified food system is effective for addressing short-term food security needs, it is important to recognize that it may not provide the full spectrum of diversity necessary for long-term food security, nutrition and health. Therefore, alongside this simplified approach, there should be a broader strategy to transition affected communities back to more diverse and sustainable food system as they recover from the crisis. This dual approach, incorporating simplified food system for immediate relief and a longer-term plan for recovery and resilience, is key to addressing food security challenges in crisis situations (FAO, WTO, and WB, 2023).

Food assistance in times of crises: the case of Lebanon

In Lebanon, the confluence of the economic crisis, currency devaluation, and food price inflation precipitated a dire food security situation. Reports by the World Food Programme (2022) and the Integrated Food Security Phase Classification (2022)

illustrate the escalating food insecurity in the country. The ongoing economic turmoil is expected to persist, exacerbating food prices and undermining individuals' ability to afford essential necessities. These reports reveal that a substantial proportion of the Lebanese population experienced inadequate diets and food insecurity in 2021 and 2022, with the situation projected to deteriorate further in 2023. Coping strategies have become commonplace, including food-based and livelihood-based measures (Integrated Food Security Phase Classification, 2022; World Food Programme, 2022).

Collectively, these reports highlight the inextricable link between food insecurity, unemployment, fragile livelihoods, limited access to education and healthcare, and the erosion of purchasing power. Notably, even substantial levels of cash assistance have encountered diminishing effectiveness in the face of reduced purchasing power, inflation, unfavorable currency exchange rates, and surging food prices. Thus, addressing the underlying causes of food insecurity in Lebanon becomes paramount, necessitating sustained humanitarian interventions that focus on augmenting household incomes and enhancing access to nutritious and affordable food for all Lebanese residents (Integrated Food Security Phase Classification, 2022; World Food Programme, 2022).

Objective of the study

This research aims to assess changes in food security in Karantina following the August 4th explosion, focusing on assistance and support provided.

We therefore set out to describe the changing socio-demographic and food security situation of the permanent households of the Karantina neighborhood, immediately after and 2 years after the Beirut port explosion.

Materials and methods

Study area

Karantina, a neighborhood near the Port of Beirut, was severely affected by the Beirut blast in August 2020. Historically a low-income community, it currently houses some of Lebanon's poorest families and Syrian refugees. This region was already facing economic, pandemic-related, and post-explosion challenges, with many residents losing their jobs (ACTED, 2020).

Karantina's population includes Palestinians, Lebanese Christians, Syrian refugees, and migrant workers. It has two main residential zones: Al-Saydeh (Christian majority) and Al-Khodor (Lebanese Sunni Muslims and Syrian refugees). The neighborhood's infrastructure is inadequate, lacking public transportation and social facilities (Beirut Urban Lab, 2021).

Following the explosion, humanitarian organizations swiftly mobilized to provide aid. Non-governmental organizations (NGOs) and volunteers extended assistance in the form of food distribution, housing repairs, and monetary aid. Nonetheless, with the passage of time, humanitarian organizations gradually phased out their support, leaving Karantina's residents, much like the rest of Lebanon, grappling with the persisting economic crisis (Beirut Urban Lab, 2021). Due to

its elevated vulnerability and the substantial impact of the explosion, Karantina was selected as the focal point of this research.

Study population and sample

This study targeted permanent household residents in Karantina. Eligibility criteria mandated that households be permanent residents of Karantina and that interviewees be adult males or females aged between 18 and 65, possessing familiarity with the household, and the capability to provide responses to inquiries concerning socio-demographics, food security, and dietary habits.

A systematic approach was used to select a sample of 100 households (33% of the population) from approximately 300 in Karantina (Beirut Urban Lab, 2021). Face-to-face interviews were conducted covering household demographics, food security, and food consumption. The data was gathered at three distinct time points to facilitate the comparison of residents' food intake and food security before, during, and 2 years after the explosion. This approach enabled the examination of the explosion's impact on the households.

Data collection

Data were collected via an online app, Survey123, in February and March 2022, covering three periods: pre-explosion (6 months before the explosion, using recall), during the explosion (6 months after the explosion), and almost 2 years after.

After introducing the project to each of the 100 heads of household, interviews were conducted using five questionnaire modules:

- 1 Socio-demographic: A set of 30 questions explored socio-economic characteristics and demographics, including household size, education, employment, income, expenditures, and debt.
- 2 Assistance Received After the Explosion: Four yes-or-no questions aimed to understand the type of assistance received in Karantina following the explosion.
- 3 Food Insecurity Experience Scale (FIES): This scale, developed by the FAO, comprises eight yes-or-no questions to assess individuals' ability to access sufficient food. The cutoff points used in this study are based on the global standard: 0–3 indicates food security, 4–6 indicates moderate food insecurity, and 7–8 indicates severe food insecurity (Food and Agriculture Organization of the United Nations, 2013).
- 4 Food Consumption Score (FCS): This indicator assessed food consumption and dietary diversity using nine distinct food groups. The adjusted cutoff points used were: 0–28 for poor food consumption, 28.5–42 for borderline food consumption, and >42 for acceptable food consumption (World Food Programme, 2008).
- 5 Livelihood Coping Strategies (LCS-FS): These strategies assessed how households respond to food shortages or insufficient funds for food purchases, categorized into stress coping, crisis coping, and emergency coping (World Food Programme, 2021b).

Statistical analysis

STATA/SE 15.1 was used for statistical analysis. Significance was determined using *p*-values ($\alpha=0.05$) and 95% confidence intervals (95% CI). Chi-square and logistic regression were used to assess significant differences and associations.

Limitations

The study is constrained by several limitations, notably a small sample size of only 100 households, which hinders the ability to detect significant changes over time and assess the impact of assistance on food security. While suitable for a descriptive community case study, the sample size is insufficient for running a multivariable model and thus adjusting for confounders. Consequently, the study is limited to examining associations rather than causations. Additionally, due to the small sample size and the absence of variability in the FCS 6 months post-explosion and the FIES 2 years post-explosion, a bivariate logistic regression was deemed unsuitable. Consequently, the application of bivariate logistic regression was restricted to the FCS at the two-year mark and the FIES at the six-month mark. Thus, a simultaneous analysis within the same timeframe was not feasible.

Results and discussion

Socio-demographic indicators

Eighty of the hundred households identified as Lebanese, while 20% were of Syrian nationality (Table 1). Household composition is shown in Table 1, with larger households predominating; 40% of households consisted of more than five occupants. Educational attainment levels among the heads of households were generally middle to high, with 41% having attained middle to high school education, and 18% having a university-level education (Table 1).

When comparing the socio-demographic characteristics of permanent residents in the Karantina neighborhood 6 months after the explosion with those 2 years later, several noteworthy trends emerge. There was a slight decrease in unemployment, dropping from 57 to 54% over 2 years. The income landscape shifted, with a decline in the percentage of households with no income (from 42 to 31%) and an increase in middle-income earners (from 5 to 19%), although fewer households earned above the minimum wage of \$118 in 2022 (from 49 to 29%). Most notably, the percentage of residents with debt surged from 18 to 53% over the two-year period, reflecting a significant financial challenge faced by the community in the aftermath of the explosion.

Six months after the explosion, everybody received food assistance, and 76% of the population received cash assistance. Whereas, 2 years after the explosion, all households did not receive food assistance nor cash assistance.

Food security indicators

Acceptable food consumption decreased from 97% 6 months prior to the explosion to 30% 2 years after. In parallel severe food insecurity increased from 3% to 34% over the same time period (Table 2).

TABLE 1 Socio-demographic characteristics of the permanent residents of Karantina 6 months after and 2 years after the explosion.

Variable	Categories	% 6 months post-explosion	% 2 years post-explosion
Household size	1–2	28	28
	3–4	32	32
	≥5	40	40
Nationality	Lebanese	80	80
	Syrian	20	20
Education of head of household	Never attended	8	8
	Elementary	33	33
	Middle/High School	41	41
	University	18	18
Employment of head of household	Yes	43	46
	No	57	54
Income quintiles	Low	42	31
	Lower-Middle	0	10
	Middle	33	19
	Upper-Middle	5	25
	High	20	15
Food expenditure quintiles	Low	22	31
	Lower-Middle	29	15
	Middle	14	18
	Upper-Middle	31	16
	High	4	20
Total expenditure quintiles	Low	24	20
	Lower-Middle	19	20
	Middle	22	22
	Upper-Middle	18	18
	High	17	20
Food assistance	Yes	100	0
	No	0	100
Cash assistance	Yes	76	0
	No	24	100
Debt	Yes	18	53
	No	82	47

Dietary changes in the population 6 months and 2 years after the explosion were examined. Significant changes were observed in the following food groups, fruits, vegetables, and pulses from 6 months after to 2 years after the explosion.

Household consumptions of food groups is shown in [Figures 1, 2](#), showing worsening consumption over time. Six months post-explosion, many households consumed fruits, vegetables, and pulses more than four times per week; with 33, 71, and 39%, respectively. In contrast, 2 years after the explosion, fruits were mostly consumed less than one time per week; 85% of the households consuming fruits less than one time per week. As for vegetables and pulses, most of the households were consuming them between two to three times per week; with 70% and 93%, respectively ([Figures 1, 2](#)).

We investigated the socio-demographic correlates of adequacy of food consumption score 2 years after the blast. A significant negative

association was observed between household size and adequate FCS, and debt and adequate FCS. In contrast, a significant positive association was identified between adequate FCS and Lebanese nationality, household income, and receipt of cash assistance ([Figure 3; Table 3](#)).

We investigated the socio-demographic correlates of food insecurity 2 years after the blast. A significant negative association was detected between household size and indebtedness when considering the Food Insecurity Experience Scale (FIES). Conversely, FIES was significantly positively correlated with Lebanese nationality, the educational attainment of household heads, and the receipt of cash assistance. The purchasing power of a population significantly influences their food security, especially in times of crises. Vulnerable, low-income populations, who are often the hardest hit by disasters and crises, frequently face prolonged recovery periods. There is a strong association between food security and that other factors like

TABLE 2 Food Consumption Scores and Food Security during the three time periods as reported by the permanent residents of Karantina.

Food security indicators	Categories	6 months before the explosion (% of households)	6 months after the explosion (% of households)	2 years after the explosion(% of households)
FCS	Poor FCS	1	0	4
	Borderline FCS	2	4	66
	Acceptable FCS	97	96	30
FIES	Food Security	80	71	2
	Mild food insecurity	17	29	64
	Severe food insecurity	3	0	34

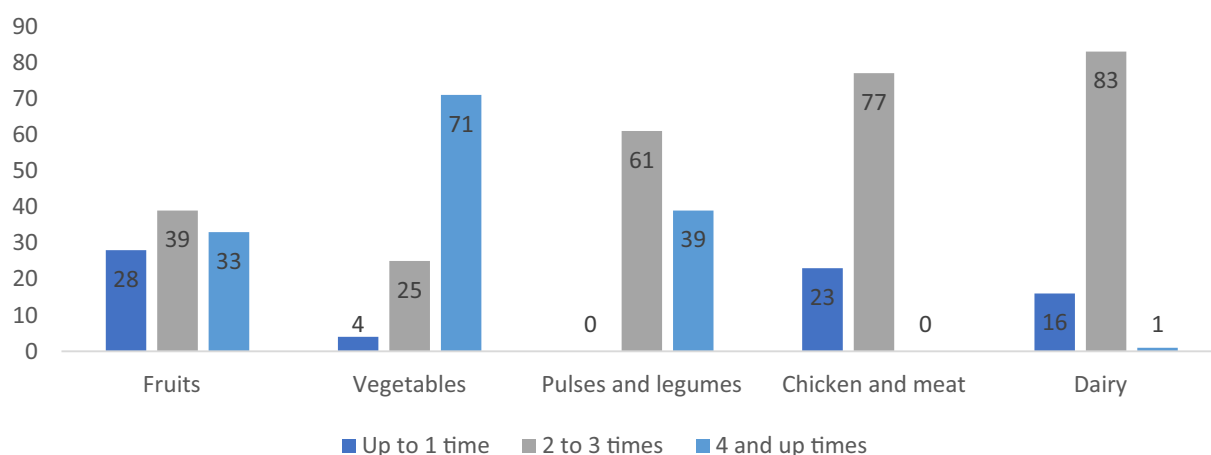


FIGURE 1
Frequency of household food groups consumption 6 months after the explosion.

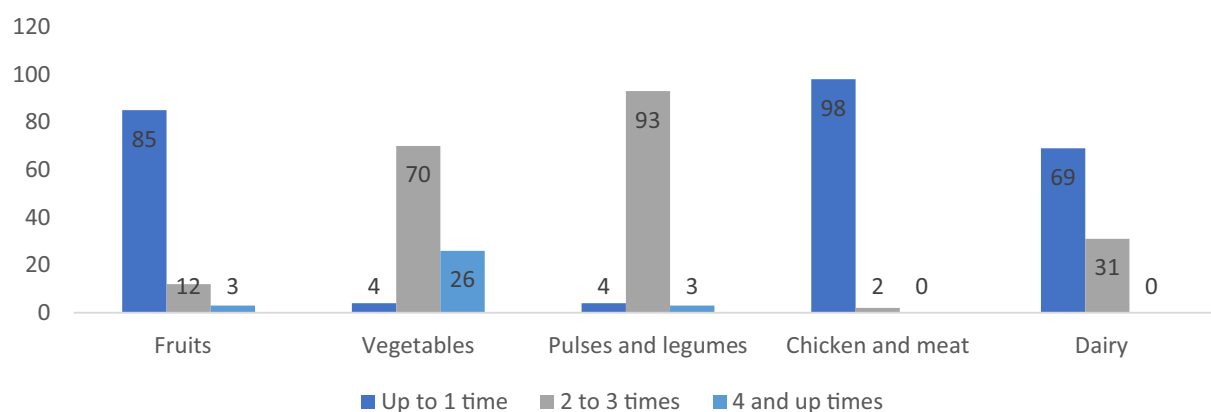


FIGURE 2
Frequency of household food groups consumption 2 years after the explosion.

education, employment status, and income levels are intimately linked to food security status (Ahmadi and Melgar-Quinonez, 2018).

A significant positive correlation was found between cash assistance and food security, indicating that that receiving cash assistance increased the odds of being food secure. This association allows cash assistance to emerge as a viable intervention in crisis contexts (Daniels and Anderson, 2018; Parvez et al., 2022; Table 4).

Livelihood coping strategies

The Livelihood Coping Strategies (LCS-FS), developed by the World Food Programme, were used to identify coping strategies among the Karantina population (World Food Programme, 2022). This tool assesses household food security and categorizes results into three levels: stress coping, crisis coping, and emergency

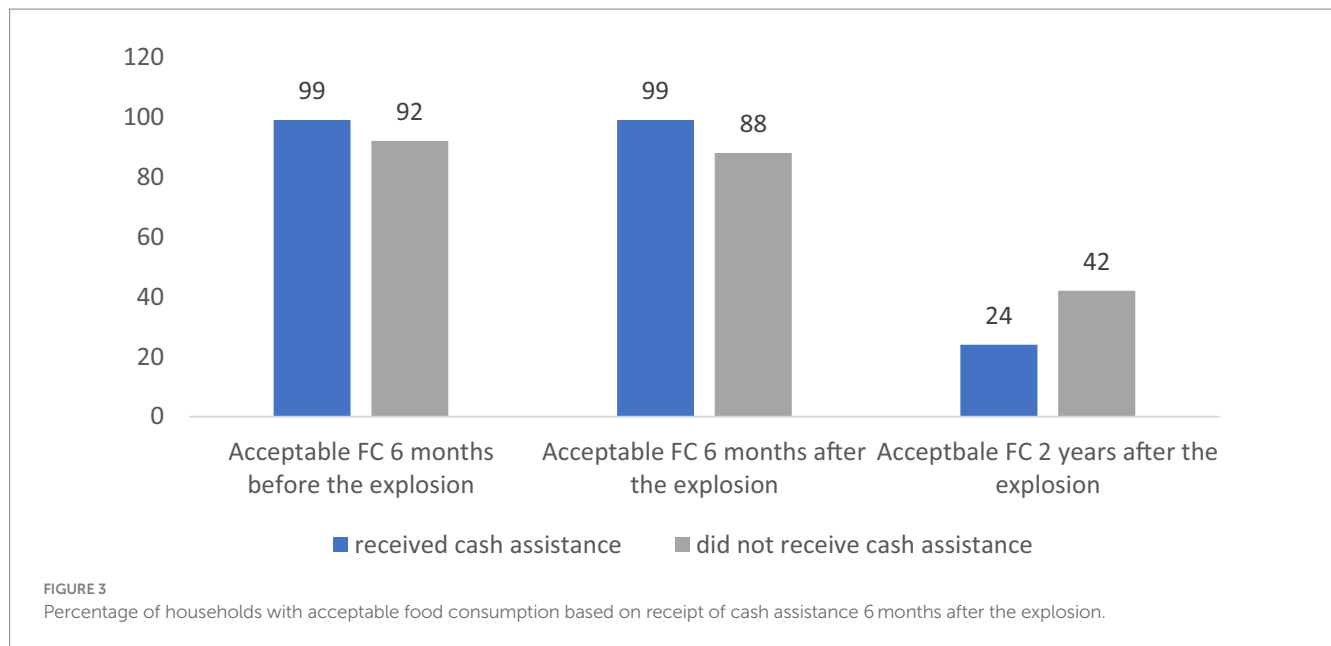


TABLE 3 Bivariate logistic regression between socio-demographic variables and adequate food consumption score 2 years after the explosion.

Variable	Categories	Odds ratio ¹	p-value ²
Household size	1–2	0.86	0.706
	3–4	0.16	0.006*
	≥5	0.43	0.111*
Nationality	Syrian	0.11	0.003*
	Lebanese	4.33	0.061*
Household income	Low income earner	0.29	0.003*
	Middle income earner	1	1.000
	Highest income earner	2.25	0.139*
Debt	No	0.62	0.112
	Yes	0.37	0.034*
Cash assistance	No	0.71	0.416
	Yes	10.71	0.045*

¹Odds Ratio (OR) is a measure of association between an exposure and an outcome. An OR greater than 1 indicates increased odds of association (more likely to occur). An OR equal to 1 indicates no association. And an OR less than 1 indicates decreased odds of association (less likely to occur). ²A value of p is a measure used in statistical hypothesis testing to determine the evidence against a null hypothesis. It represents the probability of obtaining observed or more extreme results, when the null hypothesis is true. In general, a lower value of p suggests stronger evidence against the null hypothesis, leading to the rejection of the null hypothesis in favor of an alternative hypothesis. Typically, a significance level is chosen, and if the value of p is below this threshold, the results are considered statistically significant. *means that the values are significant (above the threshold alpha).

coping strategies. Stress strategies, include using savings, borrowing money for food, and selling furniture, indicate reduced resilience. Crisis coping strategies, including withdrawing children from school or reducing education and health expenses, hinder future productivity. Emergency coping strategies, include taking high-risk jobs or involving children in income generation, and are the most extreme and difficult to reverse (VASyR, 2021; Table 5).

Six months after the explosion, 8% of the population were not adopting any coping strategies, 51% of the population were adopting stress coping strategies, 40% of the population were adopting crisis coping strategies, and 2% of the population were adopting emergency coping strategies.

Whereas, 2 years after the explosion, one household was not adopting any coping strategies, 3% of the households were adopting stress coping strategies, 94% of the households were adopting crisis coping strategies, and 2% of the households were adopting emergency coping strategies.

Discussion

Six months after the explosion, all the households received food assistance and 76% of the households received cash assistance. The immediate provision of food aid following the Beirut explosion initiated a phase of simplified food system within the Karantina

TABLE 4 Bivariate logistic regression socio-demographic variables 6 months after the explosion and food insecurity.

Variable	Categories	Odds ratio	p-value
Household size	1–2	8.33	0.001*
	3–4	0.3	0.104*
	≥5	0.16	0.008*
Nationality	Syrian	1	1
	Lebanese	3.21	0.025*
Education of head of household	Never attended	0.6	0.484
	Elementary	4.44	0.072*
	Middle/Highschool	3.21	0.145*
	University	28.3	0.008*
Debt	No	3.31	0.000*
	Yes	0.24	0.009*
Cash Assistance	No	1.18	0.683
	Yes	2.72	0.041*

*means that the values are significant (above the threshold alpha).

TABLE 5 Livelihood coping strategies during the two time periods as reported by the permanent residents of Karantina.

Livelihood coping categories	6 months after the explosion	2 years after the explosion
None	8	1
Stress coping	51	3
Crisis coping	40	94
Emergency coping	2	2

neighborhood, profoundly impacting consumption patterns and household reliance on external support. This aligns with studies by [Castetbon et al. \(2011\)](#) and [Tranchant et al. \(2019\)](#), which discuss the initial stages of aid distribution in crisis-stricken regions, emphasizing its pivotal role in stabilizing food access but potentially restricting dietary diversity due to reliance on provided items.

The data from the study revealed a stabilization in food consumption patterns immediately post-aid distribution. In the 6 months following the explosion, none of the households had poor food consumption, and 96% of the households had acceptable food consumption. These findings resonate with findings from the research by [Susanty et al. \(2023\)](#), suggesting aid-induced stability in meeting basic nutritional needs within disaster-affected communities.

However, as aid gradually diminished over time, the food system transitioned back to its usual complexities, mirroring findings in studies by [Norwegian Refugee Council \(2023\)](#) and [Caritas \(2023\)](#), which highlight the challenges faced by communities when aid ceases or diminishes. Two years after the explosion, none of the households reported receiving food or cash assistance. In addition, 72% of the population had poor food consumption, and 28% had acceptable food consumption ([Figure 3](#)). The declining receipt of aid indicates a reemergence of challenges related to food access and choices, signifying the community's return to navigating diverse but potentially limited food options ([Falb et al., 2020](#)). While cash assistance initially contributed to a positive correlation with improved food security, the absence of sustained support resulted in a regression to the previous vulnerabilities of the food system ([Figure 5](#)). The

temporary nature of cash assistance became evident as the community faced difficulties in maintaining the gains achieved during the aid period. As depicted in [Figure 5](#), the graph illustrates the sustained stability of food security among recipients of cash assistance, after the explosion. Food security, being an outcome of the food system, remained resilient as long as cash assistance was provided, highlighting the dependence of resilience on financial support. However, upon cessation of cash assistance, the observed decline in resilience suggests that the fostering of resilience may not solely be attributed to cash assistance itself, but rather to factors such as the amount and duration of cash assistance.

This underscores the need for comprehensive and long-term interventions that address the root causes of food insecurity and enhance the resilience of the food system beyond immediate relief efforts that are created in a SEFS. The findings align with the broader discourse on the limitations of short-term aid in fostering lasting improvements in food security and emphasize the importance of sustained initiatives for building a resilient food system ([Haji and Himpel, 2024](#)). Studies by [Daniels and Anderson \(2018\)](#), [Romano et al. \(2020\)](#), and [Susanty et al. \(2023\)](#) reveal that cash assistance positively impacts food consumption and dietary diversity in crisis-affected areas such as West Bank, Gaza, and Syria, respectively. Additionally, while another study, [Falb et al. \(2020\)](#) found improvements in food security in Syria with cash assistance, concerns arose about the sustainability of these gains once the program ends. Despite recognizing the immediate benefits, all studies emphasize the need for longer-term interventions for sustainable enhancement of food security and livelihoods, particularly in crisis-driven areas.

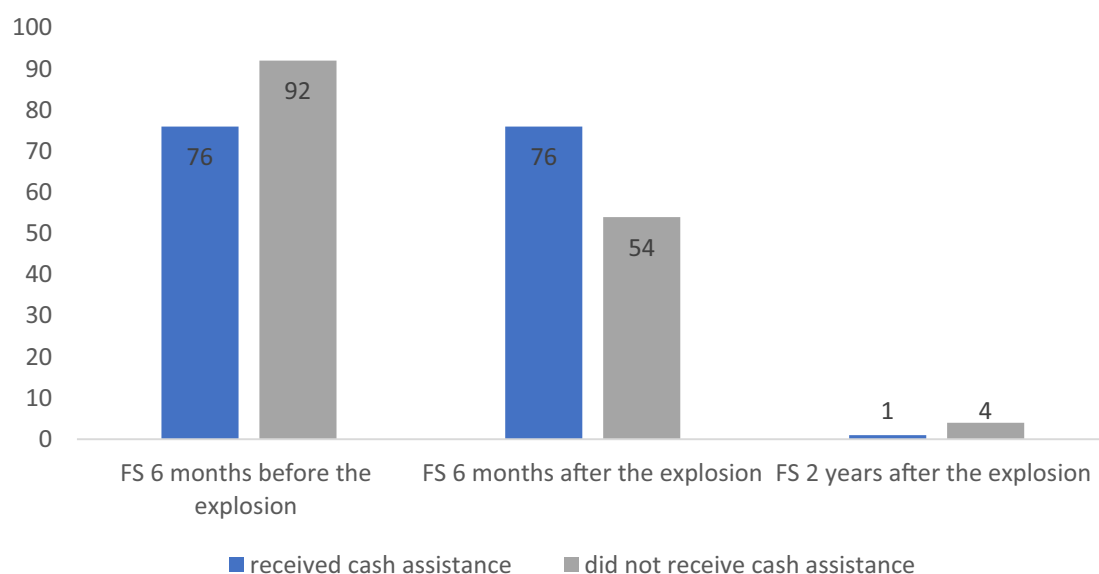


FIGURE 4
Percentage of food secure households based on receipt of cash assistance 6 months after the explosion.

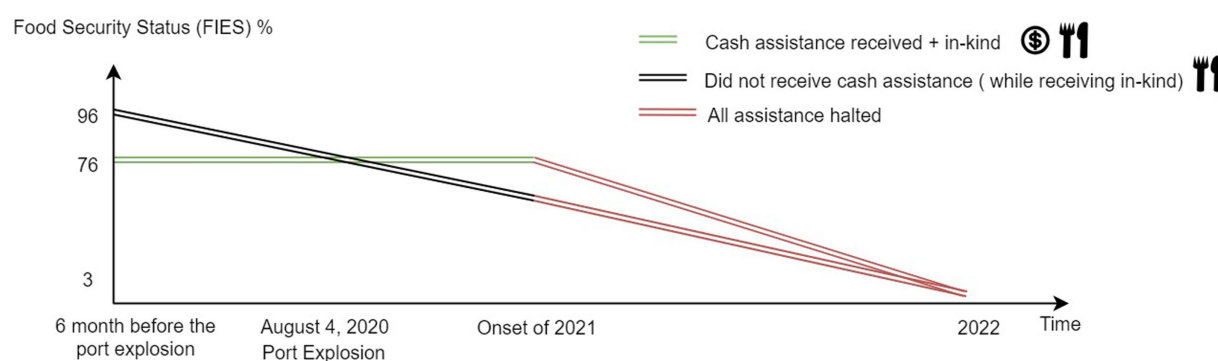


FIGURE 5
Food security status variation in relation to the time of the explosion and assistance received (graphical synthesis by authors).

Two years post-explosion, there has been a notable reduction in the intake of high-micronutrient foods and high-quality animal proteins compared to the time of the explosion. In 2022, a substantial percentage of the population, namely 97%, exhibited a frequency of less than three times per week in the consumption of fruits and pulses, while 70% reported a parallel infrequency in vegetable consumption. Additionally, diminished frequencies were recorded in the consumption of meat (100%) and dairy products (83%), all falling below the three-times-per-week threshold. The observed shift in food consumption patterns over time is common in post-disaster settings (Hoteit et al., 2021; Hunter et al., 2022). This emphasizes the necessity for adaptive dietary habits as households navigate varying food availability and affordability, consistent with findings in similar contexts.

The concerning increase in food insecurity levels over the two-year period emphasizes the vulnerability of communities facing prolonged crises (Tawodzera, 2011). Two years after the explosion, the percentage of households with mild food insecurity increased to 64%,

and severe food insecurity appeared in the population with 34% being severely food insecure (Figure 4). The rise in severely food-insecure households underscores the urgency for sustained support mechanisms stressing the prolonged impact of crises on food security (Parvez et al., 2021).

The transition in coping strategies from stress to crisis coping mechanisms highlights adaptive mechanisms in response to changing food dynamics post-aid distribution, emphasizing on the importance of understanding evolving coping strategies within crisis-affected communities (Bekele and Abdissa, 2015). From 6 months to 2 years after the explosion, the use of crisis coping strategies increased from 40 to 94%. This is evident in the adoption of the following coping mechanisms 2 years after the explosion: 81% of households sold their goods because of the lack of food or money to buy food, 74% spent some or all their household savings, 97% of households reduced expenses on health, and 94% of households bought food on credit.

However, despite the high prevalence of coping mechanisms, it is noticeable that the Mediterranean diet is profoundly embedded within

the cultural and habitual practices of the inhabitants in Karantina. Following the termination of assistance, nutrient-dense foods experienced a decline in dietary inclusion; however, staples of the Mediterranean diet, namely vegetables and legumes, persisted. Notably, the consumption of vegetables and legumes maintained prominence even among households employing severe coping strategies and pushed further into poverty. This dietary adaptation involved a shift away from meat, with individuals substituting meat with increased reliance on legumes and vegetables.

Long-term recovery strategies should emphasize enhancing access to diverse and nutritious foods, rebuilding economic stability, and fostering community resilience. Building upon existing literature, the observed shifts post-aid cessation underscores the necessity for sustained support mechanisms beyond immediate assistance (Camealeon, 2020; Falb et al., 2020; Susanty et al., 2023).

Conclusion

In conclusion, the study reveals the immediate impact of food aid in stabilizing food access following the Beirut explosion in the Karantina neighborhood. Aid distribution led to a phase of simplified food system and a subsequent stabilization in consumption patterns. However, as aid diminished over time, the food system reverted to its usual complexities, resulting in increased food insecurity levels 2 years post-explosion. Our hypothesis was accepted; cash assistance successfully maintained resilience of the food security status within the Karantina community. Despite being implemented for a brief duration, cash assistance proved effective in catalyzing income sources and, consequently, facilitating the rebuilding of livelihoods. The data also indicates a shift in dietary patterns, with reduced consumption of high-nutrient foods and high-quality animal proteins. The observed increase in severe food insecurity underscores the short-term benefits of a simplified food system for vulnerable communities facing prolonged crises. The transition in coping strategies from stress to crisis coping mechanisms further emphasizes the adaptive nature of communities in response to changing food dynamics post-aid distribution. The findings underscore the need for sustained support mechanisms beyond immediate aid, advocating for long-term recovery strategies that enhance access to diverse and nutritious foods, rebuild economic stability, and foster food system resilience.

Exploring the long-term impact of cash assistance programs on vulnerable populations at a national level is essential, with a focus on understanding how sustained financial support contributes to lasting food security. These findings also emphasize the importance of well-organized cash assistance following the explosion. Entities responsible for aid distribution should have implemented effective monitoring and evaluation measures, examining how individuals utilized the received cash, whether it covered essential needs like food, was allocated for education-related expenses, or invested in initiating small businesses. Additionally, investigating the efficacy of livelihood improvement strategies alongside cash assistance is crucial for designing comprehensive interventions.

Overall, the study's findings align with existing literature, highlighting the profound influence of food aid and its subsequent cessation on food system dynamics, consumption patterns, food security levels, and adaptive coping strategies within crisis-affected communities. However, some key questions arise for further

exploration, including the efficiency and financial feasibility of longer-term interventions, the role of technology in enhancing program effectiveness, gender dynamics, and comparative analyses between cash assistance and livelihood improvement strategies. These considerations are crucial for determining the precise amount of cash assistance required and establishing criteria for discontinuing and resuming fund distribution by organizations. It is essential to note that the decision-making process is tied to donor funding availability rather than solely being driven by the actual needs of the community. Exploring this dynamic is vital for research efforts aiming to shape policies, impacting not only those of the state but also those of non-state entities.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Human Research Protection Program (HRPP). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

MM: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. NA: Formal Analysis, Methodology, Project administration, Resources, Supervision, Writing – original draft. AY: Methodology, Project administration, Software, Supervision, Writing – review & editing. HG: Conceptualization, Data curation, Investigation, Methodology, Supervision, Writing – review & editing. YA: Project administration, Supervision, Writing – review & editing. RZ: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft.

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The spatial effects of the household's food insecurity levels in Ethiopia: by ordinal geo-additive model

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Background: Food insecurity and vulnerability in Ethiopia are historical problems due to natural- and human-made disasters, which affect a wide range of areas at a higher magnitude with adverse effects on the overall health of households. In Ethiopia, the problem is wider with higher magnitude. Moreover, this geographical distribution of this challenge remains unexplored regarding the effects of cultures and shocks, despite previous case studies suggesting the effects of shocks and other factors. Hence, this study aims to assess the geographic distribution of corrected-food insecurity levels (FCSL) across zones and explore the comprehensive effects of diverse factors on each level of a household's food insecurity.

Method: This study analyzes three-term household-based panel data for years 2012, 2014, and 2016 with a total sample size of 11505 covering the all regional states of the country. An extended additive model, with empirical Bayes estimation by modeling both structured spatial effects using Markov random field or tensor product and unstructured effects using Gaussian, was adopted to assess the spatial distribution of FCSL across zones and to further explore the comprehensive effect of geographic, environmental, and socioeconomic factors on the locally adjusted measure.

Result: Despite a chronological decline, a substantial portion of Ethiopian households remains food insecure (25%) and vulnerable (27.08%). The Markov random field (MRF) model is the best fit based on GVC, revealing that 90.04% of the total variation is explained by the spatial effects. Most of the northern and south-western areas and south-east and north-west areas are hot spot zones of food insecurity and vulnerability in the country. Moreover, factors such as education, urbanization, having a job, fertilizer usage in cropping, sanitation, and farming livestock and crops have a significant influence on reducing a household's probability of being at higher food insecurity levels (insecurity and vulnerability), whereas shocks occurrence and small land size ownership have worsened it.

Conclusion: Chronically food insecure zones showed a strong cluster in the northern and south-western areas of the country, even though higher levels of household food insecurity in Ethiopia have shown a declining trend over the years. Therefore, in these areas, interventions addressing spatial structure factors, particularly urbanization, education, early marriage control, and job creation,

along with controlling conflict and drought effect by food aid and selected coping strategies, and performing integrated farming by conserving land and the environment of zones can help to reduce a household's probability of being at higher food insecurity levels.

KEYWORDS

panel data, Markov random field, tensor product, unobserved heterogeneity, spatial effect

Introduction

The Food and Agriculture Organization (FAO) of the United Nations defined that “food security is achieved when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (1). Households with lower nutritious food intake compared to food secured households are related to food insecure and vulnerable households (1). The adverse effects of food insecurity on mental health, increased risk of being stunted, wasted, and obesity on children, and having type 2 diabetes (2, 3) are typical. The impact of food insecurity also extended to low human development, leading to higher poverty and inequality (4), along with low immunity and less productivity (5–7).

Recent global shocks, notably the US–China economic trade war, the global pandemic “COVID19” (3, 8–12), and the Russia–Ukraine (9, 13) war, have increased the risk of the food security of households in every country worldwide (14). In addition to the gradual decline in food security since 2014 (15), these shocks resulted in 928 million food insecure people in 2020, an increase of 148 million compared to 2019 (15). Furthermore, there are 122 million more hungry people in 2022 than before the COVID-19 pandemic (16) and 3.4 million additional stunting cases in 2022 due to COVID19. The global hunger range is between 702 and 828 million in 2021 (3). As close to the main driver factor, the higher proportion of food insecure reside in countries exhibits conflicts and wars (15). This region also contributes 80% of the global stunted population (2, 15). Moreover, the chronologically declined global severe food insecurity prevalence and other malnutrition problems (2) are inflated mainly after COVID-19 pandemic (3, 15, 17), and the estimated increase in food insecure people population in 2020 is equal to that of the previous 5 years combined (3, 15).

Primarily, the developing countries, such as African (52%), Asian (34%), and Latin American (9%), cover larger proportion of global food insecure population (2) mainly due to climate change (15, 18). In addition to vast intra and extra country conflicts in Africa, the frequent occurrence of drought in the region has been the major cause of crop and livestock losses (89%) (19), which leads

the continent to take a larger proportion of severe food insecure population (2). The prevalence of food insecurity is high (42%) in East Africa (20), especially Ethiopia faced food insecurity for many years; from 1979/80 and 1995/96 (21), in recent years (22) especially from 2019 to 2021 more than half (56%) of the total population suffered from moderate or severe food insecurity (23).

Currently, the bottleneck problem of Ethiopia is “the poor and large population.” In Ethiopia, 68% of the population faced multidimensional poverty (24) and the population is over 117 million in 2021 (109). Among them, 78% resides in rural areas, relying on traditional farming methods that are prone to climate change (25). The influence of global shocks, such as global pandemic “COVID19,” US–China economic trade war, and Russia–Ukraine war, and the internal conflicts (primarily on the Northern and Western Ethiopia) leads millions of people to relocate (110) and frequent droughts (111) and collectively aggravates the food insecurity. These circumstances lead to more than 20 million people experiencing hunger and requiring rapid aid from World Food Program (WFP), FAO, and other aid organizations (109).

Several studies conducted in the country indicated that conflict and drought factors, such as land size, dependency ratio, credit services, family size, household assets, number of livestock, fertilizer usage, employment, household head age, sex, education, and social protection program (26, 27), can affect the household's food security (28–34). For food insecure countries, including Ethiopia, with the advantage of the two greatest potential resources, i.e., “the people and the productive land and water,” efficient usage of these resources by investing both people and productivity can mitigate the food security problem (1, 35, 36). In addition to the numerous investigation results on the country's food insecurity, Ethiopia is a traditional country where the cultural ceremonies and religious events bring a different feeding pattern to the usual feeding culture. The food insecurity is not yet evaluated using the recommended locally adopted cut-points for the food consumption score (FCS) measure of WFP, considering that the local factors effect resulted in a divers feeding pattern (e.g., exclusion of small amounts of food items from the diet during measurement extends to include sugar and oil consumption) (37, 38). Furthermore, very few studies in the country evaluated the non-linear effects of the covariates (22, 39) without considering the spatial effects. Moreover, even though similar comprehensive global studies, such as spatial correlation of food security in developing countries (18) and in China (39), have been conducted, the effect of local factors on food insecurity level cut-point is not considered.

Therefore, in this study, to give a deeper insight, we hypothesize that neighboring zones are more likely in the food security level

Abbreviations: AgSS, Annual Agricultural Sample Survey; DIC, Deviance information criterion; EAs, enumeration areas; CSA, Central Statistical Agency; FAO, Food and Agriculture Organization of the United Nations; FCSL, Levels of Food insecurity; GAMMs, Generalized Additive Mixed model; GRFs, Gaussian random fields; GCV, Generalized cross-validation, GAM, Generalized Additive Model; MCMC, Markov chain Monte Carlo; MRF's, Markov random field; WFP, World Food Program.

than any other zones, and we need to assess the comprehensive linear and non-linear effects of geographic, environmental, and socioeconomic factors on each corrected levels of household's food insecurity. The study aims to provide comprehensive perspective, helping us to clearly understand the distribution nature of the household's food insecurity levels across administrative zones and identify key determinants among comprehensive factors influencing households at different levels of food insecurity dynamics. This information enable us to cluster the hot spot zones of food insecurity and vulnerability for area-specific mitigation using key factors.

We can apply the statistical models those have been widely used in research on the dynamics of households with food insecurity. In modeling such phenomena, the non-linear regression model, such as structured additive regression (STAR) models, alleviates the restriction that the model coefficients are constant in both linear and non-linear effects for different parts (quantiles or categories) of the distribution of y (given x), extending to include the geographical effects (40–47). In the Bayesian perspective, the empirical Bayes (EB) is preferred to full Bayes (FB) when achieving convergence of MCMC (Markov chain Monte Carlo) samples becomes a challenge. This choice is influenced by its fast optimization and unbiased estimation of the variance parameters, i.e., geo-additive models (48–52). Therefore, a novel model, i.e., the empirical Bayesian geo-additive model, by Augustin et al. (53) has been applied in this study.

From the exploratory analysis of the response variable, we observed the possible non-linear effect of continuous covariates across the response category, varying across administrative zone effects. This study aims to assess the distribution nature of the household's food insecurity levels across the administrative zones and identify key determinants from geographic, environmental, and socioeconomic factors, which contribute to different levels of locally adjusted food insecurity measures, using the ordinal geo-additive mixed model.

The remaining part of the paper is organized as follows: The method section incorporates the data sources, explanatory variables and the response considered in the analysis, and the software and the models employed; the result section interprets the main and significant outputs from descriptive and inferential statistical methods; the discussion section includes the result with respect to the existing literature; and finally, the conclusion section presents the main conclusions from the empirical result and correspondingly points out relevant interventions for policy implementation.

Methods

Data

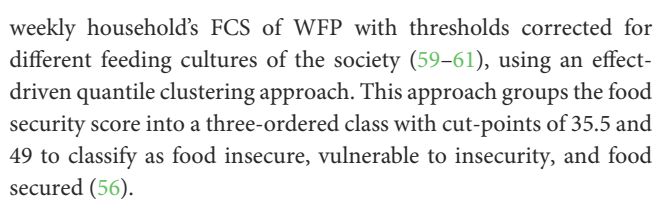
This study analyzed a total sample size of 11505 households (the three-term household-based panel data for years 2012, 2014, and 2016), which covers the whole regions of the country given by the study area plot as shown in Figure 1A. This study comprises a total sample size of 3,835 households, obtained through two-stage probability sampling across 64 administrative zones with three replications (enumeration areas and households). After removing,

two times, longitudinally missed values (a household has only surveyed once in survey years), missing values are imputed or treated by longitudinal mean for longitudinally missed values in the response or explanatory variables and by mean imputation for households with missing values in some explanatory variables. In the first stage of sampling, 333 enumeration areas (290 rural and 43 urban) were selected using simple random sampling from the sample of the Annual Agricultural Sample Survey (AgSS) enumeration areas (EAs). The AgSS EAs were selected based on probability proportional to size of the total EAs in each region. This approach considers the population size of the populous regions for sufficient representation (Amhara, Oromiya, SNNP, and Tigray) even though some under representation has been observed for unpopulous regions (Afar, Benshangul Gumuz, Dire Dawa, Gambella, Harari, and Somalie regions). The second stage is selecting 3,969 households by simple random sampling from the enumeration areas with a response rate of 99.3%. The survey was designed to be implemented in a three-round timeframe based on the AgSS field schedule—the 1st round from September to October in 2011, 2013, and 2015; the 2nd round from November to December in 2011, 2013, and 2015; and 3rd round from January to April in 2012, 2014, and 2016. The data from households were collected using both paper-assisted personal interview (PAPI) and computer-assisted personal interview (CAPI) methods with minimal problems encountered such as limited electricity availability for re-charging the CAPI tablets during the fieldwork. The data source is the Ethiopian Socioeconomic Survey (ESS) of the World Bank data set, which is the first panel data in Ethiopia collected using a project of World Bank and CSA of Ethiopia that quantify household-level food security and related factors in rural and urban (small and medium towns) areas.

Variable and measurements

The food security measurement is an ongoing problem, with various studies proposing and employing different measurement scales. This aspect includes a continuous, three-class ordinal scale or binary classification based on food consumption score (FCS) (1, 29, 54, 55). For more informative assessments and applications of policy interventions, instated of continuous and dichotomized response as food secure and insecure, this study applied ordinal food insecurity levels (FCSL), i.e., food-secure, vulnerable to food insecure, and food-insecure household (1, 56). In addition to the WFP's standard food consumption scale formulated based on 7 of days household food intake with cut points 21 and 35, to classify as food insecure, vulnerable, and secured; based on society dieting culture and pattern different cut point are recommended such as WFP recommend 28 and 42 for community sugar and oil consumption is 5 to 7 days a week (57), for Jordan households the FCS cut points used are 45 and 61 (58), and Baumann et al. (59) used 32 and 43 as cut points by excluding small amounts of food items.

As a traditional, historical, and religious country, Ethiopia has very large diet diversity in addition to various condiments and small amount of foods consumed during cultural ceremony and religious events. Hence, the response variable of this study is the



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the Eigenvalue (>1), the proportion of variance explained from the total variance, and the subjective meaning of highly contributing components (62, 63) were used to reduce the dimension of geographic variables from 19 to 6 components explaining 76.12%, similarly 12 agricultural variables combined into 4 components explaining 53%, and 47 assets variables merged into 12 components explaining 50.11% of the total variance.

Model

The food insecurity level (FCSL_i) is a categorized version of a latent continuous variable of the original food consumption score, say D_i which is truncated normal, $D_i = \eta_i + \epsilon_i$, where η_i is a predictor depending on covariates and parameters, and ϵ_i is an iid $n \times 1$ error vector, for $I = 1, 2, \dots, 11505$. The two variables, FCSL_i and D_i , are linked by FCSL_i = r if and only if $\theta_{r-1} < D_i \leq \theta_r$, $r = 1, 2, 3$, with an ordered threshold $-\infty = \theta_0 < \theta_1 < \theta_2 < \theta_3 = \infty$, for $\theta_1 = 35.5$ and $\theta_2 = 49$. Since the categorical response is a categorized version of a continuous latent response, the proportional-odds cumulative-probit model is selected. Therefore, FCSL_i can be modeled by a threshold model with a cumulative probit link for $r = 1, 2$ as follows:

$$\begin{aligned} p(\text{FCSL}_i \leq r) &= P(D_i \leq \theta_r) = \\ P(\eta_i + \epsilon_i \leq \theta_r) &= P(\epsilon_i \leq \theta_r - \eta_i) = F(\theta_r - \eta_i) \\ \Rightarrow p(\text{FCSL}_i \leq r) &= P(\epsilon_i \leq \theta_r - \eta_i) \end{aligned} \quad (1)$$

Similarly, Equation 1 can be given by $p(\text{FCSL}_i \leq r) = F(\theta_r - \eta_i)$,

where F is the distribution function of the error variable ϵ_i of D_i , by assuming that errors are Gaussian, i.e., $\epsilon_i \sim N(0, 1)$, leading to a cumulative probit link. However, the logit link also brings a closer result. The threshold model and cumulative probit link with an additive predictor extended to consider spatial effect, called a geo-additive mixed model (53). The geo-additive predictor given by the mixed model can help to detect non-linear covariates effect, structured spatial and random effect. Literature also indicated that the logit link can be an alternative, but the result obtained from cumulative logit and probit models for binary response (extended to ordinal) is usually quite close to each other (64, 65).

The geo-additive mixed model with empirical Bayes estimation is used to estimate an ordinal response predictor (η) to assess the zone-level structured and unstructured spatial distribution and the possible non-linear effects of covariates [see, (49, 66)] given by

$$\eta = \mathbf{X}^T \gamma + f_1(z_1) + \dots + f_p(z_p) + f_{unstr}(s) + f_{str}(s), \dots \quad (2)$$

where $\mathbf{X} = x_1, \dots, x_q$ are categorical covariates of $n \times p$ matrix modeled by a linear function; $\gamma = q \times 1$ vector of linear effects, $\mathbf{Z} = z_1, \dots, z_p$ are continuous covariates of $n \times p$ matrix modeled by a non-linear function $f_1, \dots, f_p$, where $f_j(z_{1j}), \dots, f_j(z_{nj}) = f_j = Z_j \beta_j$.

Predictor model Equation (2) is an extended additive model by considering the spatial effects at an administrative zone level, and it can be split into strong correlation effect f_{str} (smooth, structured) and unstructured effect f_{unstr} (local correlation accounts for unobserved locally varying covariates). A rationale behind this split is that a spatial effect is usually a surrogate of many unobserved influential factors, some of them may obey a strong spatial structure, and others may be present only locally (49). The spatial information is given by zone map “connected geographical areas” and zone coordinates. We want to test the hypothesis that neighboring zones are more likely in the food security level than any other zones.

The spatial modeling is conducted by using two neighboring methods. The spatial contingency is fitted by *Markov random field* (MRF) using zones neighborhood map (50), while spatial distance is fitted by the $k(=4)$ -nearest neighbors weighting method using a tensor product of zone longitude and latitude. However, the zone-level unstructured spatial effect is fitted by the Gaussian random effect. For spatial effects, the precision matrix is given by an adjacency matrix instead of an inverse correlation matrix (kriging) (40, 41, 64, 67, 68).

Neighboring matrix: For the given geographical map, zones are defined as neighbors if they share a common boundary and are assumed to be more likely in the food security level than any other zones, and the spatial effect is modeled by MRF (50). However, for zones longitude–latitude spatial distance neighboring, the spatial effect is fitted by a two-dimensional first-order random walk prior using a tensor product of zone coordinates (longitude and latitude) (69), and four nearest neighbors are taken (69), which is a type of isotropic correlation that does not depend on the direction of neighbors (48, 50, 53, 69–71). The neighborhood matrix for spatial contingency, with a value of -1 for zones sharing a common boundary otherwise, 0; and the spatial distance (four neighbors) are obtained from the Ethiopian shapefile map “Eth_Zone_2013” and the “bnd” object “mp_zn” is created directly using functions from the R package BayesX. A two-dimensional surface smoother called stationary Gaussian random fields (GRFs) can be used as an alternative (52). However, MRFs and P-splines are preferable to GRFs from a computational point of view, because their posterior precision matrices are band matrices or can be transformed into a band matrix-like structure, which speeds up the computation (49). The two-dimensional P-splines with 3 degrees and 20 equally spaced knots are applied for estimation.

The non-linear effects of continuous covariates are modeled through Bayesian versions of penalized splines (P-splines). The non-linear effects, $f_1, \dots, f_p$, are modeled non-parametrically using P-splines with a second-order random walk penalty. The P-spline used is a linear combination of B-spline base function $B_j(x_j)$ estimated by $f(x_j) = \sum_{s=1}^{S_j} \beta_j B_j(x_j)$ (50, 72). Each of the base functions is constructed as a combination of piecewise polynomials of degree 3 defined on a set of equally spaced knots $x_{j,min} = \zeta_{j,0} < \zeta_{j,1} < \dots < \zeta_{j,k-1} < \zeta_{j,k} = x_{j,max}$ within the domain of x_j . We used 20 knots because the previous literature suggested 20 knots as a moderate larger number of knots (49, 64, 69, 72). However, the choice for number of knots should get critical attention in regression spline, because a spline with smaller number of knots may not sufficiently flexible to capture the data variability and for a spline with a significant number of knots (large variance τ^2). The

estimated curves may tend to over fit the data, and as a result, excessively rough functions are obtained. The number of knots is directly controlled by the size of the variance τ^2 . Large variance τ^2 is equivalent to large number of knots, and small variance τ^2 is equivalent to fewer number of knots. Hence, the complex problem of choosing optimal knots is replaced by the much simpler problem of finding an optimal smoothing parameter “variance τ^2 ” (49, 53, 64, 72, 73).

The probability of a specific category r for the given effect is the area under the density between θ_{r-1} and θ_r thresholds. The influence of the effects is determined by the direction and magnitude of a shift on the distribution (64, 65).

Priors: Diffuse prior $p(\gamma) \propto \text{const}$ for fixed effect, Gaussian priors for i.i.d. random effects, MRF prior for spatial effect. A prior for a function f_j is based on specifying a suitable design matrix Z_j and a prior distribution for the vector β_j unknown parameters (40, 49). Here, the prior for the first- or second-order random walks for the regression coefficients is used and defined by $\beta_{js} = \beta_{j,s-1} + u_{js}$ and $\beta_{js} = 2\beta_{j,s-1} - \beta_{j,s-2} + u_{js}$, respectively; with Gaussian errors $u_{js} \sim N(0, \tau^2)$ and diffuse priors $p(\beta_{j1}) \propto \text{const}$ or $p(\beta_{j1}) \propto \text{const}$ and $p(\beta_{j2}) \propto \text{const}$ for the initial value (47, 49, 64).

Method of estimation and model comparison

The inference is based on Empirical Bayesian, since REML estimators of variance components are less biased compared to the full Bayesian and the convergence problem is a challenge in MCMC. Here, priors are specified for the regression parameters and the hyperparameters (the smoothing parameters) are treated as fixed and estimated in advance from the data rather than from the prior, since the prior information is not sufficient on country wide household's food insecurity levels, specially specific to the corrected FCSL. The mixed model methodology estimates the regression coefficients using penalized likelihood and the variance parameter τ^2 using restricted maximum likelihood (47, 49, 50, 64).

The R software interface for BayesX called R2BayesX package (41, 64, 67) is used for analysis. The R2BayesX is introduced by Umlauf et al. (41) which adds extensive graphics capabilities. The formula interface of the BayesX model used a variety of different smoothness priors depending on the type of covariate and the prior assumptions on smoothness. In this study, a continuous covariate is modeled using random walk priors (40) with Bayesian P-splines (69). The spatial effects are captured by Markov random field priors (74) and a tensor product of two-dimensional P-splines (71). Moreover, the prior of the regression coefficients has been estimated with a constant variance derived from the data (49). Model compression is achieved using the generalized cross-validation (GCV). A model with the smallest GCV value is selected as the best fit to the data (40, 49).

Result

Descriptive statistics of the households' characteristics across the levels of food insecurity are shown in Table 1. This result indicated that 25% of the sampled households are food insecure

and 27.08% are vulnerable to food insecurity. Chronologically, the insecurity decreased from 28 % to 23% and vulnerability also shows a slight decrement from 28% to 27% from year 2012 to 2016. The global Moran's I spatial autocorrelation indicated that the food insecurity level is significantly clustered across zones.

Larger difference on the prevalence of food insecurity levels across regions was observed; specifically, the food insecurity of Somali and SNNP regions is the cold spot (12.4%) and as hot spot (39.2%), respectively, and more vulnerable households are residing in the Benshangul-Gumuz region (33.3%) and the lowest proportion is residing in the Dire Dawa region (22.6%). The spatial dependency is observed on longitudinal average of the food insecurity levels (see Figure 1B), and this result suggests that most northern and south-western parts of Ethiopia are food insecure, and most of the central and western part of Ethiopia are vulnerable to food insecurity.

Food insecurity and vulnerability are higher among rural (26.1% and 27.7%), female headed (29.9% and 29.6%), and illiterate who cannot read and write (29.5% and 29.6%) households, as opposed to their counterparts in urban areas (16.6% and 22.8%), male headed households (23.3% and 26.2%), and those can read and write (18.6% and 23.4%), respectively.

On the other hand, households that were more food insecure and vulnerable tended to face shock/s (25.1% and 27.5%), small land ownership (25.3% and 27.3%), and an unemployed head (26% and 27.7%) compared to their counterpart. Conversely, households not facing shocks (24.9% and 26.6%), no owned land (22.7% and 25.7%), having employed head (16% and 21.1%) exhibited lower food insecure and vulnerable levels. The proportion of food insecure and vulnerable households engaged in crop farming only was greater (35.6% and 29.1%) compared to those involved in livestock farming (18.6% and 23.8%) or both (24.3% and 27.1%), respectively. Similarly, the proportion of food insecure households using fertilizer was smaller (23.99%) compared to the households not using (25.80%).

Empirical Bayes geo-additive mixed model result

From extending the result of an additive model, based on the observed spatial clustering in Figure 1B) and global Moran's I spatial autocorrelation suggestion in Table 1, the spatial effect modeled by Markov random field (MRF Model) introduces smoothness and effect change, yielding a smaller GCV of 1.8221 (see Figures 2, 3, and Table 2) compared to the additive model with GCV of 1.9550 (Supplementary Figures S1, S2, and Supplementary Table S1). Additionally, the spatial covariate modeled by tensor product shows a GCV of 1.8223 for 8 knots and a GCV of 1.8224 for 20 knots. Moreover, the kernel plot of the MRF model in Figure 4 indicated that the spatial correlation effect range is wider (−1 to 1) and flatter Gaussian distribution with higher variance estimate of the spatial effect of 0.6104 (i.e., 90.04% from the total variation is explained by the spatial effect), compared to the random effects with a range from −0.4 to 0.4 and a variance of 0.0675. This indicated that model fit improvement by including random effects that account for the unobserved spatial

TABLE 1 Descriptive statistics of the households' characteristics across the levels of food insecurity (three times replicately surveyed on $n = 3,835$ households).

State of food security levels	Food insecure (0–35.5)	Vulnerable (35.5–49)	Food secure (> 49)
FCS	25%	27.1%	47.9%
Rural vs. urban	26.1% vs. 16.6%	27.7% vs. 22.8%	46.2% vs. 60.6%
Read and write (no vs. yes)	29.5% vs. 18.6%	29.6% vs. 23.4%	40.9% vs. 58%
Employed (no vs. yes)	26% vs. 16%	27.7% vs. 21.1%	46.3% vs. 62.9%
Land own (no vs. yes)	22.7% vs. 25.3%	25.7% vs. 27.3%	51.6% vs. 47.4%
Shock (no vs. yes)	24.9% vs. 25.1%	26.6% vs. 27.5%	48.5% vs. 47.4%
Sex of household head (female vs. male)	29.9% vs. 23.3%	29.6% vs. 26.2%	40.5% vs. 50.5%
Fertilizer (no vs. yes)	24% vs. 25.8%	27.1% vs. 27%	48.9% vs. 47.2%
Farm types (cropping vs. livestock vs. both)	35.6% vs. 18.6% vs. 24.3%	29.1% vs. 23.8% vs. 27.1%	35.3% vs. 57.6% vs. 48.6%
Year 2012	28%	28%	44%
Year 2014	24%	27%	49%
Year 2016	23%	27%	50%
Regions			
Afar	21.1%	25.6%	53.2%
Amhara	24.8%	30.4%	44.8%
Benshagul–Gumuz	24.4%	33.3%	42.3%
Diredwa	14.1%	22.6%	63.3%
Gambelia	18.5%	24.6%	56.9%
Harari	20%	26.1%	53.9%
Oromia	14.6%	23.1%	62.2%
SNNP	39.2%	26.8%	34%
Somali	12.4%	23.9%	63.7%
Tigray	26.2%	31.2%	42.6%

Moran's I spatial autocorrelation result of ArcGIS: Moran's Index = 1.2, and $p = 0.0000$.

heterogeneity of the zones in Ethiopia, is relatively low, hence, the focus should be on spatially structured effects.

The MRF model in Figure 5 for spatially correlated map effect (a) indicated that the majority of southern-west and northern areas of Ethiopia have higher food insecurity (red colored). This result also reveals that the greater number of zones in the south-east and north-west areas of the country are vulnerable to food security (whiten colored).

The results in Table 2, detailing the posterior mode estimates of the linear effects, reveal that factors such as illiterate or educated ($\beta = -0.2378^{***}$), employment ($\beta = -0.2054^{***}$), residing in urban areas rather than rural ($\beta = -0.3883^{***}$), fertilizer usage ($\beta = -0.1324^{***}$), and farm types either livestock ($\beta = -0.3231^{***}$) or a combination of livestock and cropping ($\beta = -0.1923^{***}$) exhibit significant reducing effects. Conversely, the shock occurrence ($\beta = 0.0683^{**}$) and small land ownerships ($\beta = 0.1566^{***}$) exhibit a significant increasing effect on household food insecurity and vulnerability.

The posterior mode estimates of the non-linear effects in Figure 2 indicate that the household's food security level showed a positive linear significant progress over years (Figure 2F).

It also presented that household size has a significant linear positive effect on a family's food security level (Figure 2D). It also depicted that the household's dependency ratio and coping strategy index have significant non-linear effects on the household's food (Figures 2A, E, respectively), whereas the effects of adult equivalence and household's head age are non-linear (Figures 2B, C, respectively), even if there is no sufficient evidence to support the statistical significant at 95% confidence level. However, the result of household age revealed the real phenomena of Ethiopian early marriage problem, wherein food insecurity increases for younger household heads and then declines for older household heads. It is known that 80% of the population resides in rural areas, where marriage is commonplace. Newly established families, with some wealth gained from their parents, struggle to fulfill their basic needs, including food consumption, renting a new house, investing assets, and supporting new born. This issue increases the food insecurity among young household heads. However, this state tend to improve after several years of hard work at their older age.

Figure 3 also showed that the component of soil property; component of agro-ecology, distance from border and related;

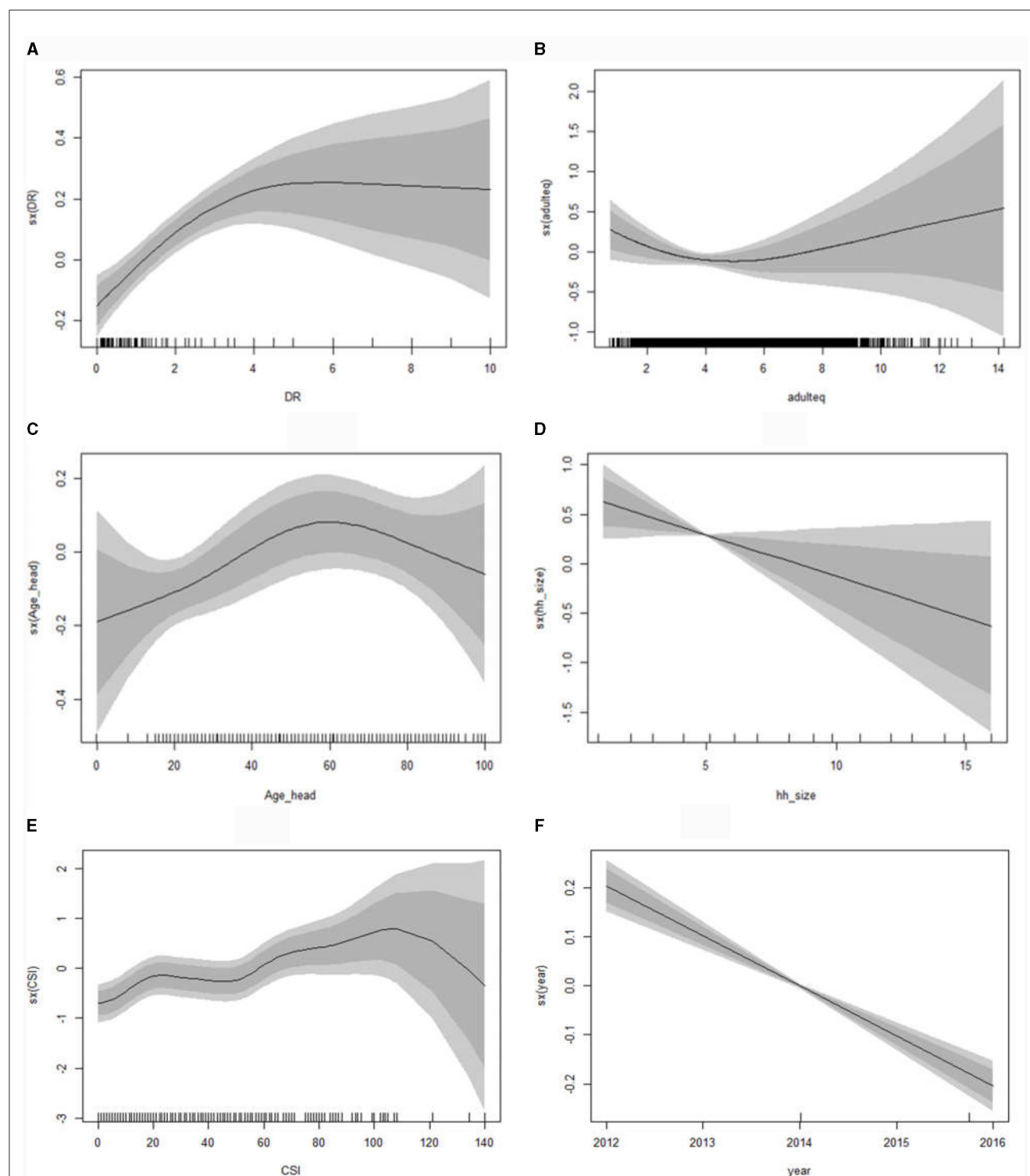


FIGURE 2

Posterior mode estimates for the non-linear effects; dependency ratio (A), adult equivalence (B), age of household head (C), household size (D), Coping Strategy Index (E), and survey year (F) (with 95% CI) on levels of food insecurity using a geo-additive model.

a component of rainfall, greenness and related; drinking water; component of non-agricultural business and related; component of agricultural package and related; and sanitation related, exhibit non-linear effects on household's food. With the exception of sanitation-related factors, all other components have a significant

effect on food outcomes (Figures 3A, B, C, D, F, G, respectively). This aspect also indicates that the component of irrigation, mixed crop, and related has a linear effect, even if there is no sufficient evidence to support the significant at 95% confidence level (Figure 3E).

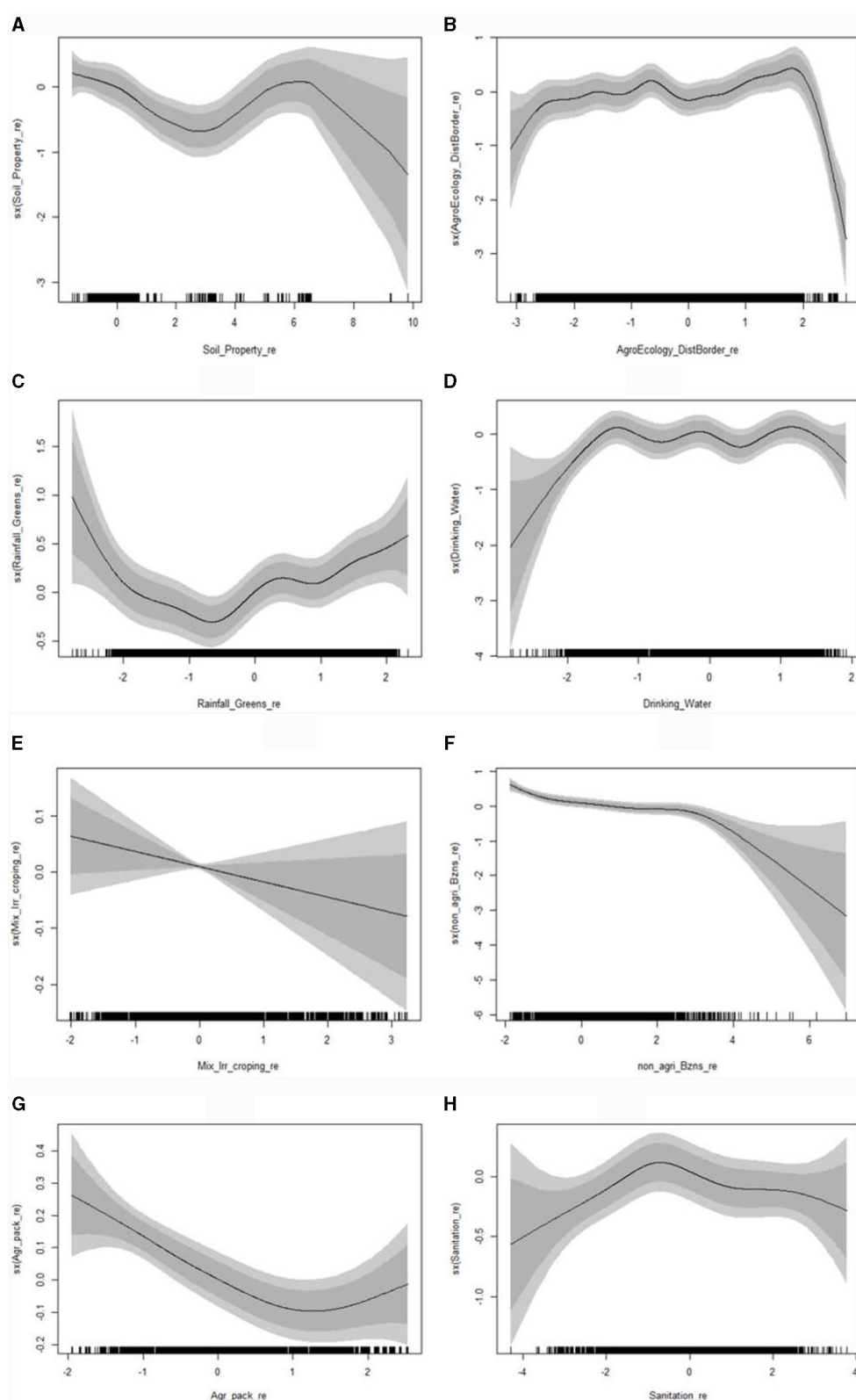


FIGURE 3

Posterior mode estimates for the non-linear effects; soil property related (A), agro-ecological and distance from border related (B), rainfall and greenness related (C), drinking water (D), irrigation, mixed cropping and related (E), non-agricultural business related (F), agricultural package related (G), and sanitation related (H) (with 95% CI) on levels of food insecurity using geo-additive model.

TABLE 2 Posterior model estimates: geo-additive model for spatial correlation modeled by Markov random field and uncorrelated effect by random effect.

Fixed effects estimation results: parametric coefficients	Estimate	Std. error	t-value	Pr(> t)
θ_1	−0.3789	0.2185	−1.7338	0.0830(.)
θ_2	0.4742	0.2186	2.1694	0.0301(*)
Urban vs. Rural	−0.3883	0.0440	−8.8324	0.0000(***)
Read and Write (Yes/No)	−0.2378	0.0262	−9.0825	0.0000(***)
Shock (Yes/No)	0.0683	0.0239	2.8600	0.0042(**)
Fertilizer (Yes/No)	−0.1324	0.0349	−3.7953	0.0001(***)
Employed (Yes/No)	−0.2054	0.0427	−4.8115	0.0000(***)
Health problem (Yes/No)	0.0281	0.0271	1.0387	0.2990
Small size land ownership (Yes/No)	0.1566	0.0424	3.6947	0.0002(***)
Farm Type: (Livestock/Cropping)	−0.3231	0.0672	4.8057	0.0000(***)
Farm Type: (Both farms/Cropping)	−0.1923	0.0407	−4.7251	0.0000(***)
Smooth terms	Variance	Smooth Par.	df	Stopped
Adult equivalence	0.0009	1126.9300	3.6938	0
Age of household head	0.0001	6961	2.2735	0
Agricultural package related	0.0001	10027.9000	2.5430	0
Agro-ecological and distance from border related	0.1081	9.2529	10.9175	0
Coping strategy index	0.0140	71.2708	5.5753	0
Dependency ratio	0.0001	6878.3100	2.3204	0
Drinking water	0.0216	46.2039	7.6259	0
Household size	0.0000	168901	1.0385	1
Irrigation, mixed cropping and related	0.0000	28818900	1.0015	1
Non-agricultural business related	0.0049	202.4790	4.7566	0
Rainfall and greenness related	0.0087	115.2580	6.5107	0
Sanitation related	0.0017	592.6620	3.9997	0
Soil property related	0.0102	97.7056	4.2269	0
Year	0.0000	4312010	1.0468	1
Structured spatial effect (MRF)	0.6104	1.6383	40.3100	0
Unstructured spatial effect	0.0675	14.8126	19.2056	0

Signif. codes: 0 “***” 0.001 “**” 0.01 “*” 0.05 “.” 0.1 “1”. N = 11,505, df = 128.046, AIC = 21694.4, BIC = 22635.6, logLik = −10719.15, GCV = 1.8221.

Discussion

The descriptive statistics indicates higher prevalence of food insecurity (25%) and vulnerability (27.08%), implying that more than half of the population had a problem of feeding (in hanger), even if positive progress in time has been observed in reducing the proportion insecure and vulnerable households. In-line with this result, the 2022 report of State of Food Security and Nutrition in the World (SOFI) showed that 56% of the total population affected by moderate or severe food insecurity between 2019 and 2021 (23), and 20 million people are in need of food by 2023 (99). Although severity of food insecurity in the country is also reported by several studies (22, 28, 29, 31, 75–77), the vulnerability is not assessed as

such. In the meantime, as the literature supports, improved food aid and safety nets programs have to be strengthened to control chronic food insecurity (23, 74, 77).

This study aims to find out the hot spot zones of food insecurity and vulnerability zones based on the spatial distribution of the household's food insecurity levels following the investigation of the contributing factors to each levels of food insecurity from geographic, environmental, and socioeconomic variables for the purpose of mitigation for each specific area/zone. Comparing to previous study conducted in developing countries (18, 54, 76–79) and Ethiopia (22, 29, 31, 34, 80, 81), this study measures the household's food insecurity levels by corrected FCSL using cut-points, which consider that local factors lead to divers feeding

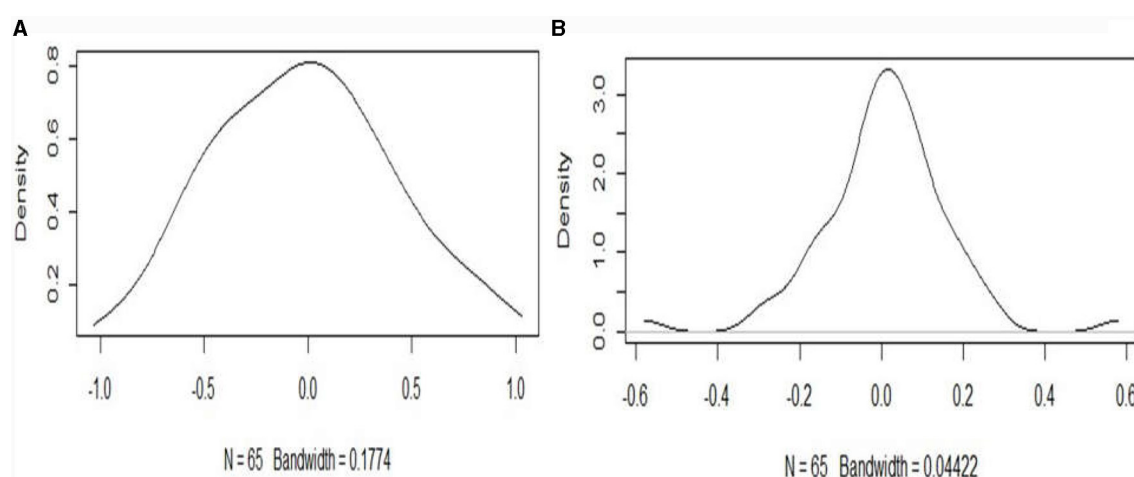


FIGURE 4
Kernel for structured (A) and unstructured (B) spatial covariate effect.

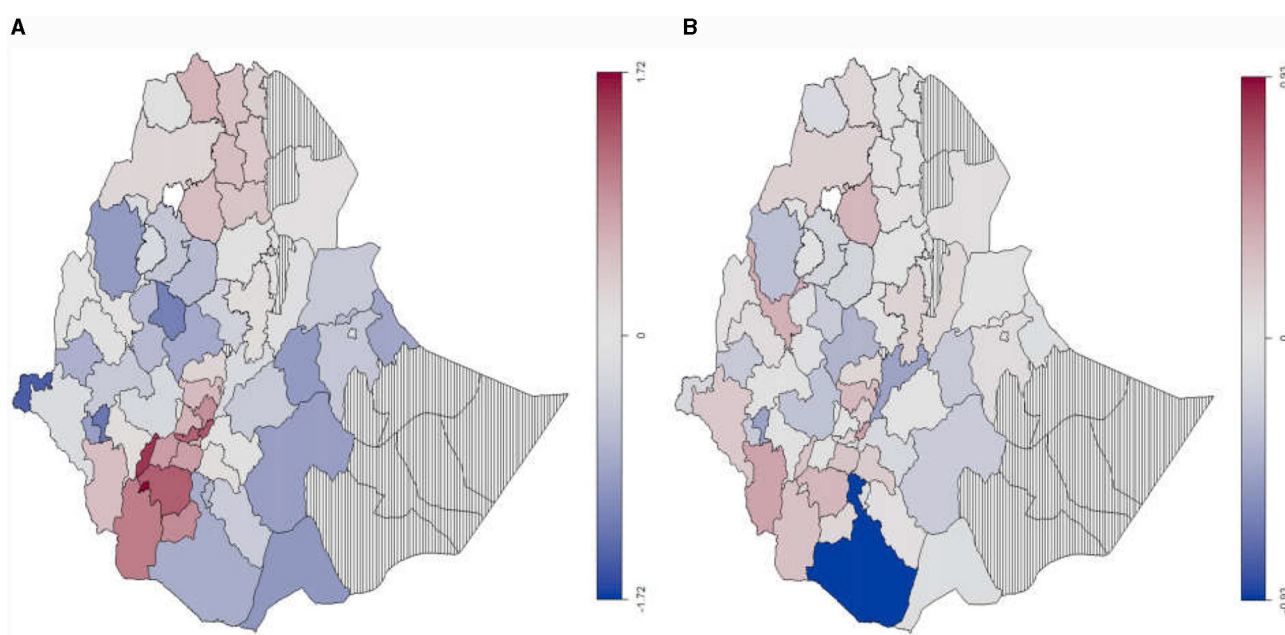


FIGURE 5
A visual representation of the posterior means for structured spatial effect fitted by Markov random field prior (A) and unstructured spatial effect fitted by Gaussian prior random effect (B) for levels of food insecurity (zones with vertical lines represent areas with no data).

pattern, analyze the non-linear effect of geographic, environmental, and socioeconomic factors, and identify causing determinants to each levels of food insecurity to implement the area-specific mitigation for hot spot zones of food insecurity and vulnerability.

Though several researches assessed the determinants of Ethiopian household food insecurity and supported the associated factors obtained in this study (31, 34, 80, 81), only few researches consider the spatial pattern in Ethiopia (22, 82, 83) with better literature on developing country (18, 84–90). However, none of literature labeled as food insecure, vulnerable, and secured based

on cut-points corrected for feeding cultural difference and provided the determinants specific to the hot spot zones of food insecurity and vulnerability.

Therefore, to assess the geographic distribution and find out the effects (linear and non-linear) of factors on household's food insecurity levels, the additive model is extended for the spatial effect using MRF and tensor product and unobserved effect by Gaussian. Using GCV, the MRF geo-additive mixed model is selected as a best fit. The advantage of introducing spatial effects to an additive model is reported by Kammann and Wand (52), and specifically,

this model is elaborated by Fahrmeir et al. (49). However, in the MRF model, the implication of the higher variance estimate of the spatial effect of 0.6104, i.e., 90.04% of the total variation, is explained by the spatially structured effect compared to the unstructured effects, indicating that the model fit improvement by including random effects that account for the unobserved spatial heterogeneity of the zones in Ethiopia is relatively low. Hence, spatially structured effects on household's food security levels should be focused. A similar suggestion had been reported by previous researches (41, 47).

The spatially structured effect result from the MRF model reveals that the majority of the south-west and northern part of Ethiopian zones have higher food insecurity and south-east and western part of Ethiopian zones are more food secured, especially Nuer zone has better food security. A similar result of the zone-level spatial effect has been suggested by Dessie et al. (22). Specifically, North Tigray, Western Tigray, Central Tigray, Southern Tigray, Wag Himra, South Gonder, North wollo, South Omo, Basketo, Gamo Gofa, Segen Peoples', Konta, Dawro, Wolayita, Gurage, Selti, Hadiya, Alaba, KT exhibit higher food insecurity. A similar result for smoothness due to considering the zone-level spatial effect is reported by Dessie et al. (22), and other studies also indicated the presence of regional variation in food security (39, 91–93). The distinguished finding from this result is that the greater number of zones in the South-East and North-West areas of the country re vulnerable to food insecurity. Actually, the unstructured spatial effect also agree on some of these results, which may be due to similarity of locally (zone level) influencing factors of vulnerability.

The posterior mode estimates of the linear effects revealed that an increase in urbanization, education, and job/employment decreases the higher food insecurity levels (food insecurity and vulnerability). The urbanization effect shows a higher magnitude in reducing higher levels of food insecurity compared to other effects. The literature also strongly supports the influence of urbanization on reducing food insecurity levels, meaning that rural households are more food insecure than urban households (22, 29, 36, 94, 95). The positive effect of education to mitigate food insecurity is indicated by previous researchers (28, 31, 32, 76, 78, 80, 91, 96, 97), and similarly, the contribution of employment to reduce food insecurity is also supported by previous researchers (31, 54, 77, 78, 80, 95, 98). Food insecurity tends to increase for younger household heads and subsequently declines for older household heads. Since 80% of the population resides in rural area where early marriage is commonplace, younger households struggle with establishing a new house, investing assets, and supporting their new born. This state increases the food insecurity during the early years of young household heads, but this situation tends to improve after several years of hard work at their older age. Therefore, early marriage poses a higher risk of food insecurity for younger household heads compared to older household heads (22, 31, 54, 80).

Farming livestock or both livestock and crop has a significant effect on reducing higher levels of food insecurity (14, 31, 54, 75, 76, 80, 95, 99). Fertilizer usage reduces the higher food insecurity levels. This result coincides with the previous study results (22, 31, 32, 75, 100).

The shock occurrence increases the higher food insecurity levels. The severe effect of shock is reported by previous studies (22, 29, 36, 94, 101, 102). Households with small land sizes are strongly positively associated with the higher levels of food insecurity. The negative effect of small land size owned households on the reduction of food insecurity is supported by previous studies (31, 32, 75, 95, 99, 102).

The posterior mode estimates of the non-linear effects indicate that the household's food security levels showed a positive linear significant progress over years. Predominantly, the significant reduction of food insecure and vulnerable households in the country has been supported by the literature (29, 103) and distinguished from the aggravation of recent years global food insecurity prevalence (3, 15). The result also reveals that the probability of being food insecure increase with the household's dependency ratio; however, at a higher level of dependency ratio (> 4), the effect keeps constant. Specifically, when a dependency ratio in a household moves from 0 to 1, the level of food insecurity turns from a negative to a positive scale, implying that the Ethiopian household's food security does not hold any dependent individual in the family. This result is supported by a similar study conducted by previous researchers (22, 29, 104–106).

The household size has a significant linear negative effect on a family's probability of being in higher levels of food insecurity because in Ethiopia agriculture is human labor based and having higher human power can help in gaining much production from farming crops and livestock in rural areas to secure family's food intake. This result is in contrast with previous studies (6, 75, 97); however, the importance of human power resources for productivity in food security is well explained by previous studies (1, 36). The strength of coping strategy shows a monotonic increasing association with the higher levels of food insecurity up to 100, but beyond that point, food insecurity steps down. Hence, the applied coping strategy depends on the severity of food insecurity. Previous research has identified that different coping strategies are applied based on the magnitude of food shortage (29, 107).

The posterior mode estimates of the non-linear effects indicated that as soil property increases, the probability of a household in higher levels of food insecurity declines at the lower level (0 to 3). However, at the middle score ranging from 3 to 6, the effect is insignificant even though the probability appears to increase again. This increase is disrupted and declines at higher scores, which may be due to soil having higher (an increased) nutrients. Oxygen can lead to higher production from farming crops and livestock. This result is supported by previous studies (80, 95).

At a higher score agro-ecological zone (> 2), a decline in the higher levels of food insecurity is observed, whereas a linear increase in higher levels of food insecurity was observed up to -2 , but from -2 to 2 , the change was not visible. This aspect implies that the temperate (colder), central, and highland areas exhibit better food security or less probable to be in a higher levels of food insecurity. This result is supported by previous studies (6, 80, 92, 94). The increase in components of rainfall and greenness declines the higher levels of food insecurity at lower values (< 0), but it rises at higher values (0 to 2). Therefore, excessive rainfall and precipitation can reduce production rather a moderate score can

help to reduce higher levels of food insecurity and helps to secure food. A similar result for the effect of rainfall and greenness on food insecurity is reported by previous studies.

The probability of the higher levels of food insecurity increases up to the drinking water score of -2 , remains constant up to 1 , but declines after reaching 1 , which implies that having drinking water source >1 leads to a significant reduction in the household's probability of being at the higher levels of food insecurity. This result is supported by a previous study (102). The previous study also indicates that a component of irrigation, mixed crop, and related has a linear positive effect on reducing a household's probability of being at the higher levels of food insecurity. The contribution of irrigation, mixed cropping, and land conservation to the reduction of food insecurity is reported by previous studies (35, 97).

An increase in non-agricultural businesses reduced the probability of a household being at the higher levels of food insecurity. However, having more than three non-agricultural businesses leads to a higher food security. The effect of more income from the non-agricultural business is reported by many studies (31, 80, 84, 97). The probability of a household being at the higher levels of food insecurity declines as agricultural package usage increases up to 2 , but using more than two agricultural package increases it and consider as wasting effort. The improvement obtained in food insecurity from agricultural package implementation is also reported by previous studies (80, 95). The probability of a household being at the higher levels of food insecurity increases when sanitation is negative (<0). Conversely, for positive sanitation, the probability declines faster, implying that a household with higher sanitation (better solid waste disposal, bathing and toilet) has a higher probability of being food secure. This result is supported by previous studies (29, 34, 96).

In general, this study assessed the spatial heterogeneity of household food insecurity levels (18, 22) and identified the underling driving factors to the hot spot zones of food insecurity and vulnerability. Hence, the higher levels of food insecurity (insecure and vulnerable) can be reduced by working on urbanization (22, 29, 36, 94, 95), education (28, 31, 32, 76, 78, 80, 91, 96, 97), reduction in young household head by combating early marriage (22, 31, 54, 80), using fertilizer in cropping (22, 31, 32, 75, 100), creating jobs/employment (31, 54, 77, 78, 80, 95, 98), farming livestock or/and crop (14, 31, 54, 76, 80, 95) agricultural package related (80, 95), soil property related (80, 95), rainfall and greenness related (34, 80), irrigation and mixed cropping and related (34, 35, 97), agro-ecological and distance from border related (6, 22, 34, 80, 92, 94), household size (1, 36), non-agricultural business related (31, 80, 84, 97), sanitation related (29, 34, 96), and drinking water (102). Controlling factors, such as shocks (22, 29, 36, 94, 101, 102), dependency ratio (22, 29, 104–106), owned low land size literature (31, 32, 75, 95, 99, 102), and using better Coping Strategy Index, can help to reduce food insecurity and vulnerability.

Strengths, limitations, and future work

Previous research on Ethiopian food security used cross-sectional data and focused on investigating the linear effects of factors on food insecurity. This paper has several strengths; this

paper used the recommended locally adjusted cut-points of WFP's FCS, and identified that deriving factor leads to the hot- and cold spot food insecure areas further to uncover the general distribution of food insecurity levels across administrative zones of the country. We have used the available data that is older than 7 years, since recent data are not yet collected by the concerned body due to many problems faced in Ethiopia including political instability, war, and displacement. On the other side, even though a large sample size of 3835 households are taken repeatedly three times in year 2012, 2014, and 2016, the model does not converge and the longitudinal correlation due to repeated measures at the household level across space/zones is not considered due to the convergence problem. Actually, the model considered that only longitudinal evolution and correlation were converged but ignoring the spatial dependency does not address the objective and lower the relevance of the result. We have also faced convergence problem for full Bayesian estimation and even though the Empirical Bayes achieved convergence by stopping criterion for small variances less or equal to $1e-05$. Therefore, as future work one can extend the work using sufficiently repeated measurements based on the panel data that will be released in the future and assess the evolutionary nature of the household level food insecurity levels across space/area. Furthermore, there is also a need for further comprehensive researches that consider cultural disparities across nations, which affect the consumption pattern to fix a universal threshold for food insecurity levels cut-points or some robust estimate.

Conclusion

The household's levels of food insecurity showed direct significant linear progress over the years. Hence, significant progressive reduction of food insecure and vulnerable households in the country has been observed.

The spatially smoothed additive model brings an advantage in identifying hot spot levels of food insecurity over the additive model by extracting effect of area/zone specific and structured determinants causing each level (insecure or vulnerable). The strong spatially correlated severe food insecurity across zones has been observed mainly in the northern and south-west parts of Ethiopia. However, the greater number of zones in the south-east and north-west areas of the country are spatially correlated vulnerable zones to food insecurity. Interventions are recommended to address spatial structure factors in these areas. Specifically, since the structured spatial effect explained the majority (90.04%) of the total spatial variation, the significant factors with large magnitude contributed a larger variance to the model. Thus, implementing policies, such as focusing on urbanization [since most rural areas are inadequately connected to urban due to low road infrastructure, farmers are out of modern inputs to achieve higher yields and sell or buy from the market (16), "targeting zone level urbanization is a key"], education, early marriage control, and job creation, can mitigate food insecurity and the vulnerability in hot spot zones. Moreover, considering the current conflict, frequent drought, population size, degraded land, and global shocks impact on the country, to meet future food security Agriculture's environmental footprint, must be controlled (108) by focusing on integrated farming for drought-resistant

crops, such as climate-smart agriculture project (15) and insurance programs for livestock (15), through environmental and land conservation. Subsequently, applying the best coping strategies (relying on less preferred foods and limiting the variety of foods eaten) can help to reduce higher levels of food insecurity. This result can help policymakers and future researchers to apply and extend the study to overcome replicated data limitations and model convergence problems by adding the next (2nd) longitudinal data and high-performance computer for better understanding of the food insecurity levels dynamics in Ethiopia.

Data availability statement

The 2011–2016 ESS data files and documentation are publicly available and can be found at: <https://microdata.worldbank.org/index.php/catalog/2053>, <https://microdata.worldbank.org/index.php/catalog/2247> and <https://microdata.worldbank.org/index.php/catalog/2783>. Further inquiries can be directed to the corresponding author.

Author contributions

HW: Conceptualization, Formal analysis, Methodology, Software, Writing—original draft. TZ: Conceptualization, Supervision, Writing—review & editing. AM: Conceptualization, Formal Analysis, Methodology, Supervision, Writing—review & editing. ZD: Data curation, Formal Analysis, Methodology, Supervision, Writing—review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2024.1330822/full#supplementary-material>

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Exploring food system resilience to the global polycrisis in six Asian countries

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The world is currently in the midst of a global food crisis brought about and exacerbated by a series of mutually reinforcing shocks to food systems. This study investigated the resilience of food systems in six Asian countries (Bangladesh, Kyrgyz Republic, Lao PDR, Pakistan, Philippines, and Sri Lanka) amidst the global 'polycrisis' caused by COVID-19, geopolitical conflicts, and climate change. Trend analyses were performed for 19 indicators sourced from global databases and World Food Programme national data, representing the four domains of food system resilience: exposure to shocks; resilience capacities and agro- and food diversity, resilience responses and strategies; and long-term resilience outcomes. The analysis revealed that all six countries experienced the effects of the 'polycrisis', leading to diverse impacts on exchange rates, with Sri Lanka, Pakistan, and Lao PDR facing significant currency depreciation. While most countries increased crop production and decreased food imports during the crisis, government economic support during the pandemic varied widely. Resilience outcomes, including national food price inflation and the proportion of populations facing food insecurity, witnessed upward variations. Overall, countries with higher resilience capacities at the start of the 'polycrisis' showed less severe long-term resilience outcomes. Our findings highlight the varied challenges and resilience capacities across each country, influenced by a complex interplay of economic, political, agricultural, and food affordability factors crucial for determining long-term resilience in their food systems. Recommendations for future research include focusing on resilience assessment in food systems, integrating climate change adaptation measures, and developing early intervention strategies.

KEYWORDS

food system, polycrisis, food system resilience, NCD-protect, NCD-risk

1 Introduction

The unfolding global food crisis, triggered by a sequence of interconnected shocks including the COVID-19 pandemic, geopolitical conflicts, and climate-induced extreme weather events, has severely disrupted food systems worldwide (1). The war in Ukraine exacerbated the strain on global supply chains, leading to critical shortages in supply stocks. Simultaneously, geopolitical shifts influenced by the conflict disrupted worldwide energy provisions, resulting in increased costs for food processing, transportation, and commodity prices (2). Climate change-related extreme

weather events further compounded these challenges, diminishing global food production and wreaking havoc on critical infrastructure (3, 4). The simultaneous occurrence of these events, defined as a ‘polycrisis’ (5), has spurred significant spikes in food price inflation and heightened food insecurity globally (6), with the Asia-Pacific region in particular experiencing swift and severe impacts (7, 8).

The region, already burdened with the world’s highest rates of all forms of malnutrition, has seen millions more people becoming acutely food-insecure in the past year (9). Supply chain disruptions, protectionist trade measures, and climate-induced events have contributed further to the region’s crisis (10, 11) and necessitates immediate attention and innovative solutions to address the unprecedented challenges.

To mitigate the crisis and enhance long-term food security against climate change and biodiversity loss, the Asian Development Bank has announced plans to provide at least \$14 billion over 2022–2025 to bolster food systems in the region (12). To ensure investments are strategically directed, it is crucial to explore how food systems have reacted to shocks, and how resilience can be enhanced to ensure long-term food security in the face of future crises.

The objective of this study was to explore the resilience of food systems to the ongoing global polycrisis in six countries in the Asia region (Bangladesh, Kyrgyz Republic, Lao PDR, Pakistan, Philippines, and Sri Lanka).

2 Methods

2.1 Conceptual framework

This study employed a conceptual framework adapted from the model developed by Fanzo et al. (13) to assess the resilience of food systems amid ongoing crises, utilizing a holistic, national-level approach,

building on work by many others (14–17). As defined by Fanzo et al. 2021, food system resilience is “the ability of different individual and institutional food system actors to maintain, protect, or quickly recover the key functions of that system despite the impacts of disturbances.”

This model of food system resilience encompasses four indicator domains: (1) exposure to shocks; (2) resilience capacities and agro-and food diversity; (3) resilience responses or strategies; and (4) long-term outcomes (Table 1).

2.2 Indicator selection and data

Indicators for each food system domain were adapted from Schneider et al. (18) and customized for the specific context of the six selected countries (Table 2). The inclusion criteria were as follows:

- **Relevance:** Indicators that could clearly be linked to the fundamental components of the food system dashboard framework (19): External Factors (drivers), Food Environments, Food Supply Chains, Individual Factors, Outcomes.
- **Availability of data:** Indicators for which data was available for both the “pre-crisis” period (2010–2019) and the “ongoing crisis” period (2020–2023), and if possible, information was available for all six countries.

The data used in this study were partially sourced from various global, publicly available data sources, including the World Bank’s Health Nutrition and Population Statistics, Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), Oxford Covid-19 Government Response Tracker (OxCGRT), EM-DAT The International Disaster Database, The Legatum Prosperity Index, and The United Nations Commodity

TABLE 1 Description of food systems resilience components (13).

Indicator domain for food system resilience	Description
Exposure to shocks	Assessment of food system resilience begins with assessing and documenting the adverse effects that affect those systems.
Resilience Capacities	Features that are expected to make a system or its actors more resilient. Characteristics include redundancy, diversity, flexibility, connectivity, anticipation, self-efficacy, or access to insurance or formal credit. Potential indicators of resilience capacities include food system actors’ adaptive capacities (e. g., connectivity, social capital), social cohesion, or measures of value chain flexibility.
Agro- and Food Diversity	Agrobiodiversity and food diversity play important roles in building resilience in crop, livestock, forest, fishery, and aquaculture production systems. Moreover, agrobiodiversity secures the resilience capabilities of food systems for future generations and yet-unknown shocks. Food diversity underpins healthy diets with most food based dietary guidelines recommending a diet that is high in food group diversity.
Resilience Responses and Strategies	Not all responses adopted by individuals, communities, or societies to anticipate or mitigate/buffer the impact of shocks and stressors result in positive outcomes, either in the short- or longer-term. Understanding and measuring resilience also requires documenting and tracking these responses as an attempt to strengthen the ability of households and society to choose what they perceive at that time as the “right” response(s), rather than being forced by circumstances or lack of information to pick options which might be detrimental overall.
Long-term outcomes	The indicators used to measure long-term outcomes should reflect these improvements in human well-being. In the context of food systems many of those improvements will revolve around food security and nutrition. Tracking the stability of the different pillars of food security (food availability, access, and utilization) could therefore be an important element in measuring food system resilience, but it could include other indicators such as the stability in the livelihoods of these involved in food system activities. The emphasis, however, should be on measuring (in)stability over time rather than absolute values.

TABLE 2 Food system resilience indicators.

Indicator domain	Sub domain	Indicator	Data source
Exposure to shocks	Economic stability	Exchange rate	FAOSTAT
	Natural disaster	Ratio of affected people to the total population	EM-DAT
	COVID-19	COVID-19 Stringency Index	OxCGRT
Resilience capacities and agro-food diversity	Food produced domestically	Crop production index (2014–2016 = 100)	World Bank
		Fertilizer consumption	World Bank
		Livestock production index (2014–2016 = 100)	World Bank
	Imported food	Food import (volume) NCD-protect Food import (volume) NCD-risk food groups	UN Comtrade
	Countries' infrastructure level	Mobile cellular subscription	World Bank
	Social capital	Social capital index	Legatum Institute / FSCI
	COVID-19	COVID-19 Economic Support Index	OxCGRT
Resilience responses and strategies	Coping strategy	Reduced Coping Strategy Index (rCSI)*	WFP
		Livelihood Coping Strategy (LCS)**	WFP
Longer-term resilience outcomes	Food price volatility	Food price inflation	FAOSTAT
		Food Price Anomalies (IFPA), by type of product (Rice)	FAOSTAT
		Food Price Anomalies (IFPA), by type of product (Wheat)	FAOSTAT
	Food supply variability	Food supply variability	FAOSTAT
	Food security	% population experiencing moderate or severe food insecurity	FAOSTAT
		% population who cannot afford a healthy diet	FAOSTAT
		Food consumption score (FCS)***	WFP

*Reduced coping strategy index: this indicator measures the frequency and severity of household behaviors when faced with shortages of food or financial resources to buy food. A higher score indicates more frequent and/or extreme negative coping strategies. Based on the score it is categorized in: No/low coping strategy (rCSI = 0–3); Medium coping strategy (rCSI = 4–18); High coping strategy (rCSI > 18). **Livelihood coping strategy: This is an indicator used to understand households' (HH) medium and longer-term coping capacity in response to lack of food or lack of money to buy food and their ability to overcome challenges in the future. Strategies can be classified into four severity groups: HH not adopting coping strategies; HH adopting stress coping strategies; HH adopting crisis coping strategies; HH adopting emergencies coping strategies. ***Food consumption score: This indicator is a composite score based on households' dietary diversity, food consumption frequency, and relative nutritional value of different food groups. It is a commonly used WFP indicator and was included despite data not being available for all six countries. Based on the score it is categorized in: Poor (FCS ≤ 28); Borderline (FCS = 28.001–42); Acceptable (FCS > 42).

Trade Statistics Database (UN Comtrade). For three indicators, the reduced Coping Strategy Index (rCSI), the Livelihood Coping Strategy-Food Security (LCS-FS), and the Food Consumption Score (FCS), publicly and non-publicly available data were provided by the World Food Program (WFP) Regional Bangkok Bureau. Through engagement with WFP country offices in the six countries, additional data sources were also identified. In cases where data for a specific indicator were unavailable, the feasibility of using one or multiple proxies was evaluated.

Data extracted from the selected global data sources, along with definitions are included in a [Supplementary Table](#).

2.3 Categorizing food import data

To analyze food import from a nutritional perspective, data from UN Comtrade were reclassified based on the 28 out of 29 food groups

outlined in the Global Diet Quality Project's Diet Quality Questionnaire (DQQ) guidelines (20). The 29th DQQ food group-fast foods - was excluded as it is not considered a food consumed for purchase at home and was therefore not available in the UN Comtrade import databases.

Following the classification of food import into DQQ food groups, these groups were further categorized into three groups based on the Global Dietary Recommendations (GDR) Score. The GDR Score is a measure based on standard, evidence-based guidelines related to foods known to either contribute to or protect from noncommunicable diseases (NCDs) (21). The three GDR food categories established for this study were: "NCD protect" foods, serving to protect against NCDs, "NCD risk" foods, known to pose a risk for NCDs, and "other foods" group, including food items classified as neither NCD-risk nor NCD-protect. The detailed classification of food groups into these three GDR food categories is described in [Appendix A](#).

2.4 Statistical analysis

To assess the impact of the shocks resulting from the polycrisis on selected resilience indicators, trend analyses were performed using data from 2010, when available, to the most recent available year of the ongoing crisis period. Microsoft Power BI's time series prediction method, known as exponential smoothing, was applied to generate forecasts and 95% confidence intervals starting from 2019. A comparison was made for each resilience indicator between the actual trend direction and the desired direction. An overview of the evolution of indicators of “resilience capacities and agro- and food-diversity,” “resilience responses/strategies” and “longer-term resilience outcomes” domains from pre-crisis to crisis period in the six targeted countries is presented in [Appendix A](#).

To further investigate changes in household food security between the “pre-crisis” and “crisis” periods, we calculated the relative percentage change in FCS from 2019. The results are presented in the form of boxplots in Section 3.4.2. “Pre-crisis” and “crisis” period data for FCS were only available for three of the six targeted countries—Bangladesh, the Kyrgyz Republic, and Pakistan.

To simplistically capture the explanatory power of the model, we examined whether countries with higher resilience capacities exhibit more favorable long-term outcomes than those with lower resilience capacities. For this purpose, values for all indicators within the domains *resilience capacities and agro-food diversity* and *long-term resilience outcomes* were assigned a rank from 1 to 6, with 6 being the most desirable score, for example having the highest crop production or the lowest food price inflation. The rankings for resilience capacities and agro-food diversity were based on values from the pre-crisis year 2019, while those for long-term resilience outcomes were based on values from the most recent available “crisis period” data. The Economic Support Index indicator, serving as a proxy for resilience capacities, was excluded from the ranking analysis due to the

unavailability of pre-crisis period data, as the indicator was developed at the onset of the COVID-19 pandemic. Each score for every indicator within each resilience domain was aggregated for each country, and the total was divided by the possible maximum score for that country, accounting for the number of indicators with missing data. In cases where two or more countries had the same value for a particular indicator, they were assigned the same rank number. Further details on the methodology can be found in [Appendix A](#).

3 Results

3.1 Exposure to shocks

3.1.1 COVID-19

COVID-19 was a major shock felt by all six countries. The COVID-19 Stringency Index ([Figure 1](#)) indicates that, while containment measures by governments were promptly and uniformly adopted across all countries to minimize the spread of COVID-19, how stringent and how long these measures were maintained varied. The Philippines and Bangladesh, although they relaxed their stringent measures after a few months from the beginning of the pandemic, maintained relatively high levels of stringency for an extensive period before gradually lifting them. In contrast, Sri Lanka and Lao PDR rapidly began to ease restrictions, adapting their degree of stringency according to transmission levels.

3.1.2 Economic stability

Significant disparities in exchange rates became evident across the countries ([Figure 2](#)). During the crisis period, the depreciation of the Pakistani currency occurring in 2018–19 persisted in 2020, leveled off in 2021, and then increased sharply by 26% in 2022. The Sri Lankan currency exhibited a steady but moderate depreciation

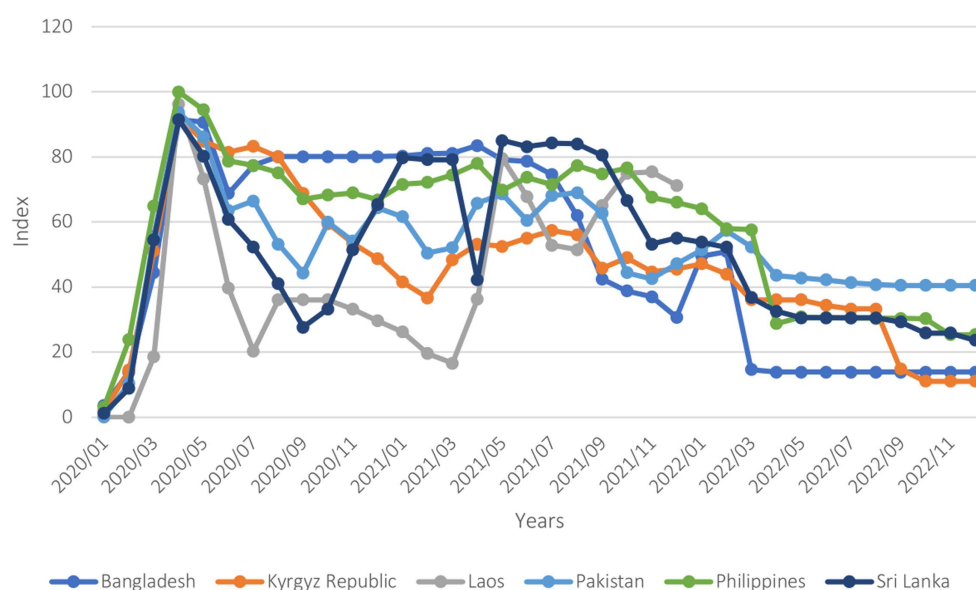


FIGURE 1

Covid-19 stringency index (January 2020–December 2022). The stringency index is a composite measure based on nine response indicators including school closures, workplace closures, and travel bans, rescaled to a value from 0 to 100 (100 = strictest).

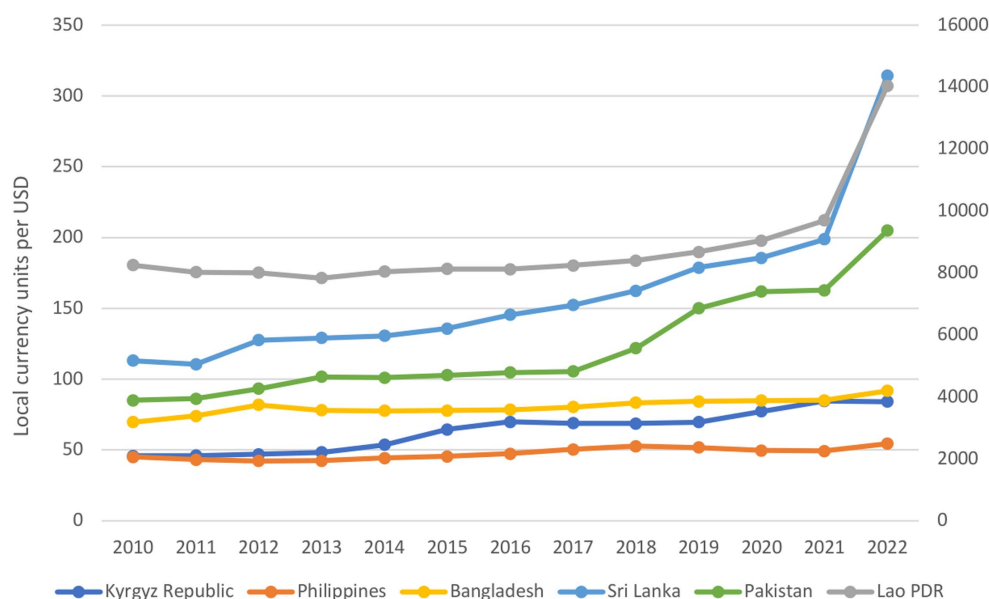


FIGURE 2

Exchange rate (2010–2022). See the primary vertical axis (0–350 local currency unit per US dollar) for Kyrgyz Republic, Philippines, Bangladesh, Sri Lanka and Pakistan. See the secondary vertical axis (0–16,000 local currency units per US dollar) for Lao PDR.

during the pre-crisis period and the first 2 years of the current crisis (2020, 2021). However, in 2022, the depreciation of the Sri Lankan currency accentuated, reaching 58%. Similarly, the Lao PDR currency slightly dropped in value in 2020–21, followed by sharp depreciation, falling by 44% in 2022. In comparison to other countries, the Kyrgyz Republic sustained a moderate depreciation, experiencing a 21% decrease from 2019 to 2022. Bangladesh and the Philippines exhibited more stable trends in their currencies, with the currency of Bangladesh depreciating by 8% and that of the Philippines by 10% only in 2022.

3.1.3 Natural disasters

In 2021, Typhoon Rai affected 11% of the Filipino population. Pakistan faced major floods in 2010 and 2022, impacting 10 and 14% of the Pakistani population, respectively. Sri Lanka confronted floods in 2011 and 2014, along with severe droughts in 2012, 2014, 2016, and 2017. In 2022, almost 5% of the Bangladeshi population was affected by damages from cyclones and floods. Lao PDR experienced adverse effects from floods and storms, particularly in 2013 and 2018. The Kyrgyz Republic was the only country where the ratio of affected people to the total population was nearly zero.

3.2 Resilience capacities and agro- and food-diversity

3.2.1 Domestic food production

The domestic crop production index revealed an increase in crop production from 2019 to the crisis period in all countries except the Kyrgyz Republic, where the index dropped from 110 points in 2019 to 98 points in 2021 (Figure 3). The increase in domestic crop production was mirrored by an increase in fertilizer consumption (Figure A in Appendix B).

The livestock production index showed a similar pattern, however a significant reduction in livestock production was observed in the Philippines (Figure B in Appendix B).

3.2.2 Food imports

Overall, the volume of food imports declined for five of the six countries with available data between 2019 (pre-crisis year) and 2021 (crisis year). At the same time, the volume of GDR-classified NCD-risk foods remained stable over the crisis period for most countries (Figure 4). Kyrgyz Republic, Lao PDR and Sri Lanka had the highest import volumes of NCD-risk food and beverages during the crisis years of the countries studied: in 2021, the Kyrgyz Republic recorded an import of 101 kg of food per 1,000 persons, while Sri Lanka registered 44 kg of food imports per 1,000 persons. In Lao PDR, the import volume of NCD-risk food and beverages was 78 kg per 1,000 persons in 2020, experiencing a decrease to 48 kg per 1,000 persons in 2021. Sri Lanka's NCD-risk import figures were high, considering that an import ban (Extraordinary Gazette No 2167/10, 2020) was as imposed in the country starting in 2020 in the wake of the COVID-19 pandemic which limited the import of thousands of food and non-food items.

In order to support the findings on food import volumes, we also examined food sales between 2017 and 2023, which mirrored the import findings. The Philippines had by far the highest sales volume of NCD-risk food and beverages across all years, indicating concern for the nutritional quality of diets. In particular, the sales volume of sugar sweetened beverages (SSB), increased in the Philippines, Kyrgyz Republic, Pakistan, and Lao PDR (Figure C in Appendix B).

3.2.3 Infrastructure level and social capital

Overall, social capital, measured by the social capital index, and infrastructure level, measured by mobile cellular subscriptions, remained relatively stable in all countries (Figures D,E in Appendix B).

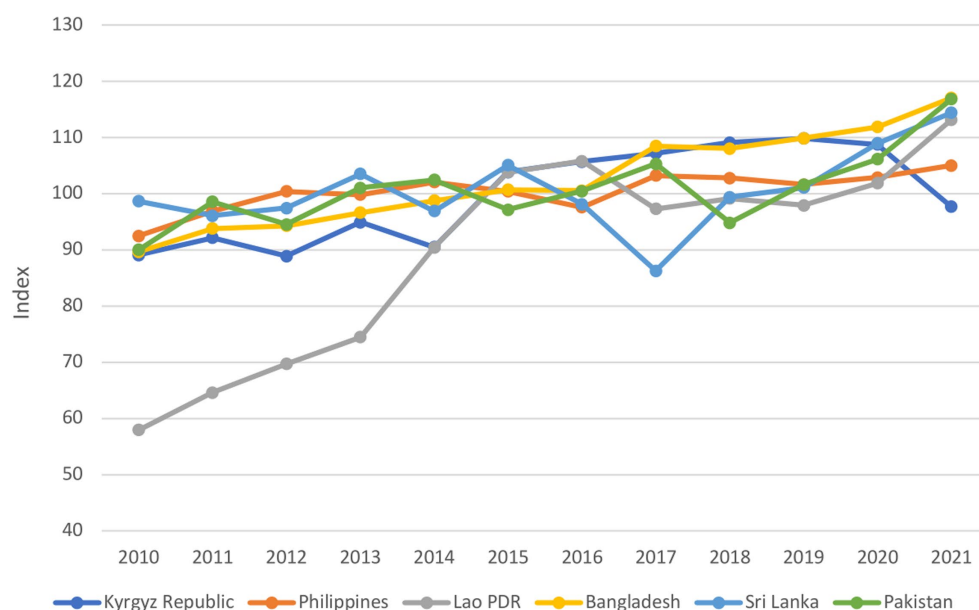


FIGURE 3

Crop production index (2010–2021). Crop production index shows agricultural production for each year relative to the base period 2014–2016.

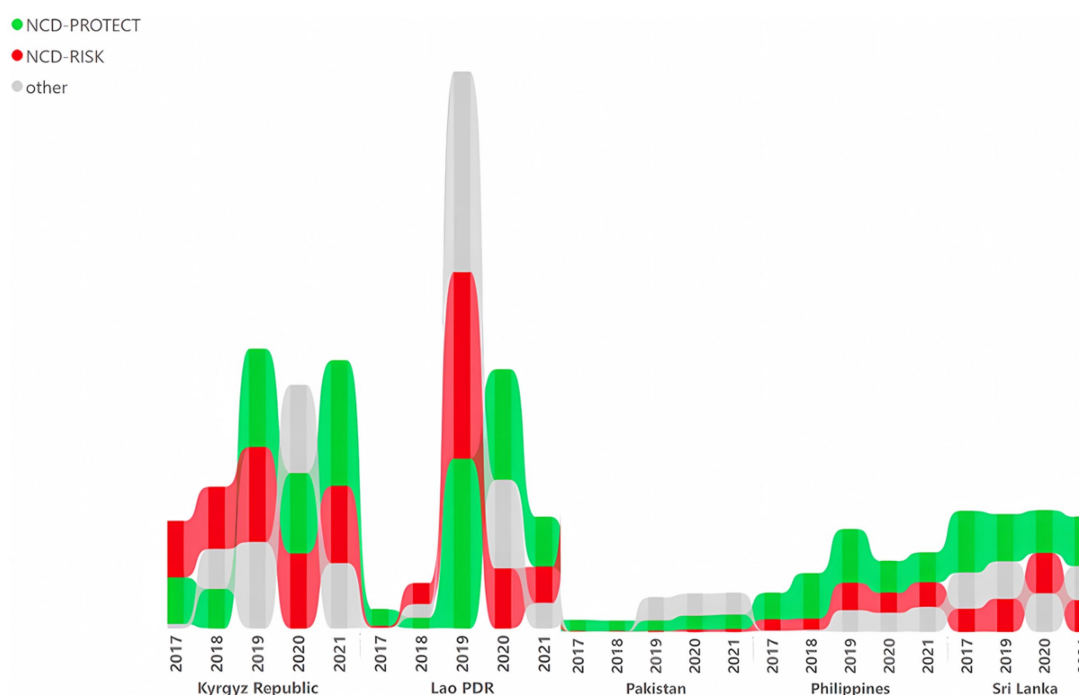


FIGURE 4

Total *per capita* volume (kilograms or liters) of imports of GDR-classified NCD-risk factor and -protect food groups. NCD-Protect: foods protective against noncommunicable diseases (whole grains; legumes/pulses; vitamin A-rich orange vegetables; dark green leafy vegetables; other vegetables; vitamin A-rich fruits; citrus; other fruits; nuts and seeds). NCD-Risk: foods related to noncommunicable diseases (baked/grain-based sweets; other sweets; processed meat; unprocessed red meat - ruminant; unprocessed red-non ruminant; packaged ultra-processed salty snacks; instant noodles; sugar-sweetened beverages). Other: white roots, tubers, and plantains; eggs; cheese; yogurt; poultry; fish and seafood; Other: 25 Fluid milk; Sweet tea / coffee / cocoa; Fruit juice and fruit-flavored drinks.

3.2.4 Economic support

The Economic Support Index (Figure 5) shows that various levels of economic support were provided by the governments of the six countries 2 or 3 months after the beginning of the pandemic. The Kyrgyz Republic

and Pakistan, despite some fluctuations over time, maintained high levels of economic support throughout the entire year of 2022. Lao PDR exhibited a similar trend, but with economic support decreasing to zero in October 2022 and then rebounding the following month, whereas the

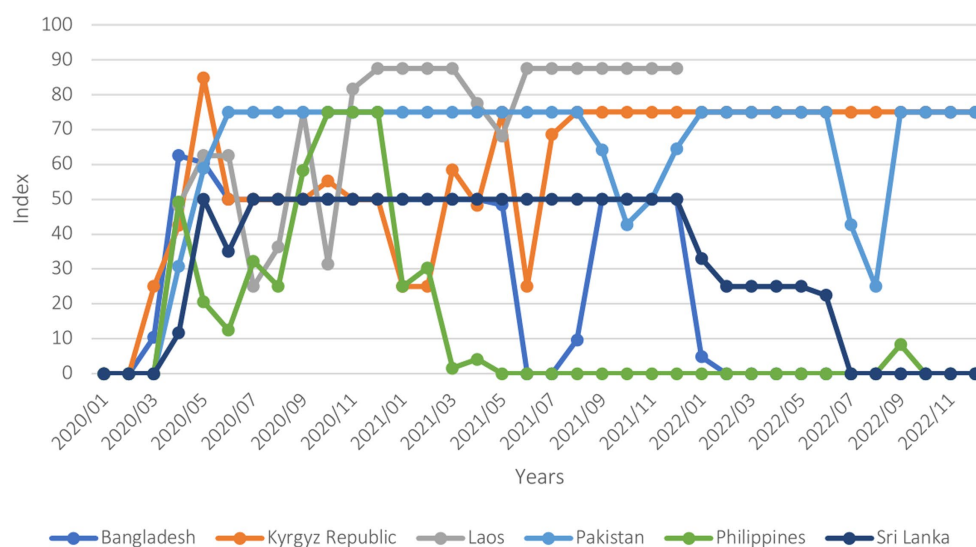


FIGURE 5

Covid-19 economic support index (January 2020–December 2022). The economic support index is a composite measure based on four indicators: direct transfers to people not working due to the pandemic; debt relief for households; fiscal spending to stimulate the economy; and international support. It is rescaled to a value from 0 to 100 (100 = highest).

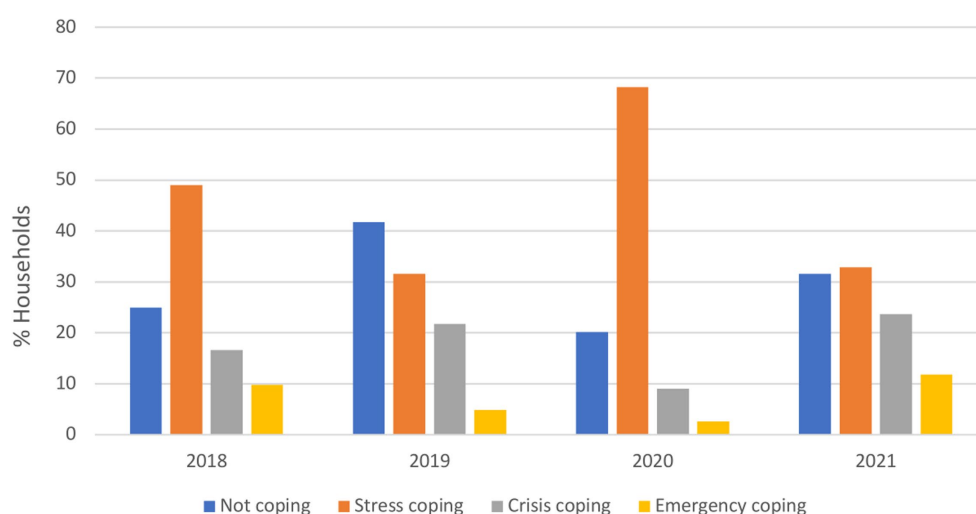


FIGURE 6

Proportion of households relying on livelihood coping strategies for food security in Kyrgyz Republic from 2018 to 2021. Stress coping strategies: indicates a reduced ability to deal with future shocks due to a current reduction in resources or increase in debts. Crisis coping strategies: directly reduces future productivity, including human capital formation. Emergency coping strategies: affects future productivity but are extremely difficult to reverse or more dramatic in nature.

Philippines provided moderate support during the early months of the pandemic, increased its support to a high level for a few months in late 2020 and quickly reduced it to minimal levels in early 2021.

3.3 Resilience responses and strategies

3.3.1 Coping strategies

Kyrgyz Republic and Pakistan were the only countries with available pre- and during-crisis data for trend analysis of coping strategy indicators. In the Kyrgyz Republic, the national average rCSI increased from a mean score of 3.8 in 2019 to 8.2 in 2021, indicating that

households relied more frequently on extreme food-based coping strategies (e.g., limiting portion size at mealtime; [Supplementary Table](#)). Regarding LCS-FS, the use of stress coping mechanisms increased in 2020 (reported by 68% of households) but returned to pre-crisis levels in 2021 (reported by 33% households; [Figure 6](#)). The use of crisis and emergency coping mechanisms escalated drastically in 2021, although they had declined in 2020. These results reflect an erosion of households' capacities to withstand shocks and future productivity. In Pakistan, the rCSI showed a decrease in "medium coping" and "high coping" categories and a sharp increase in the "low coping" category in 2020 compared to 2019 ([Supplementary Table](#)). Similarly, when looking at LCS-FS, the use of drastic coping mechanisms declined between 2019

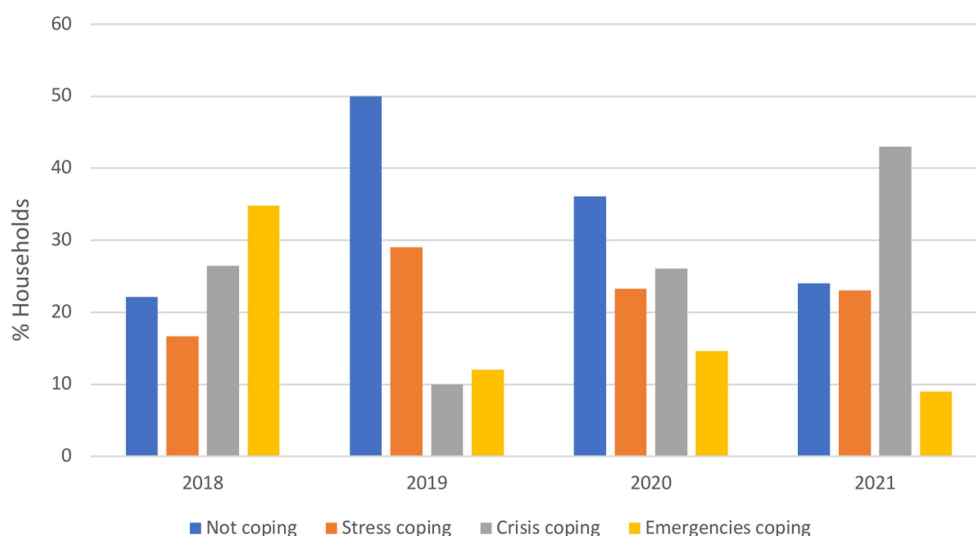


FIGURE 7

Proportion of households relying on livelihood coping strategies for food security in Pakistan from 2018 to 2021. Stress coping strategies: indicates a reduced ability to deal with future shocks due to a current reduction in resources or increase in debts. Crisis coping strategies: directly reduces future productivity, including human capital formation. Emergencies coping strategies: affects future productivity but are extremely difficult to reverse or more dramatic in nature.

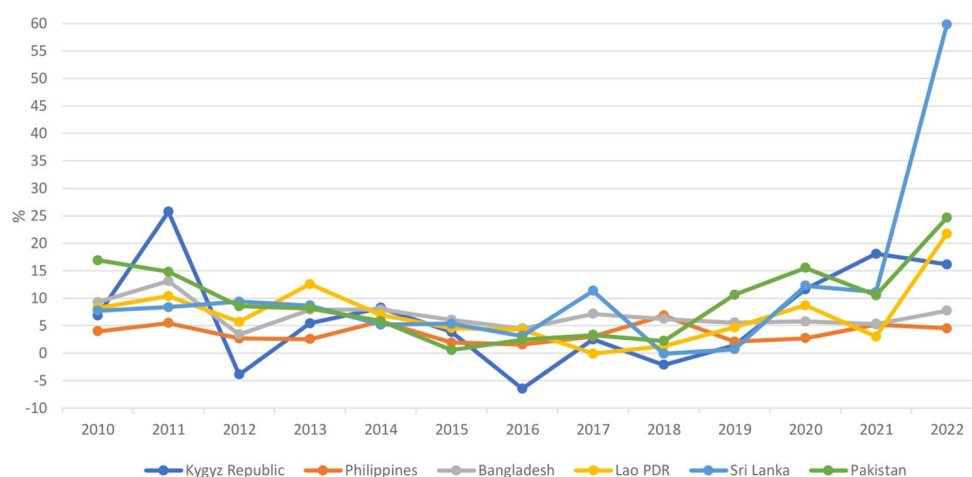


FIGURE 8

Annual food price inflation (2010–2022).

and 2020 [from 26 to 10% (crisis) and 35 to 12% (emergency)] and stress coping strategies or not at all increased (Figure 7). However, in 2021 and 2022, there was a slight decline in the use of stress and emergency mechanisms, a notable decrease in those not using any coping strategies, and a significant increase in the use of crisis strategies.

3.4 Long-term resilience outcomes

3.4.1 Food price volatility

Food price inflation in the six countries showed an increase from 2019 to the crisis period in all countries, especially in Sri Lanka, where

inflation rose to 12.3% in 2020, remained at 11.1% in 2021, and spiked to 59.8% in 2022 (Figure 8).

Analysis of food price anomalies for rice from 2015 to 2022 highlighted differences in price stability, with Bangladesh, Pakistan, and the Philippines maintaining relatively steady rice prices, while Lao PDR and Sri Lanka experienced moderate to high price growth (Figures F–H in Appendix B).

3.4.2 Food security

The prevalence of moderate or severe food insecurity increased slightly from pre-crisis to the crisis period in all countries except Bangladesh, where the prevalence remained stable. Pakistan had the

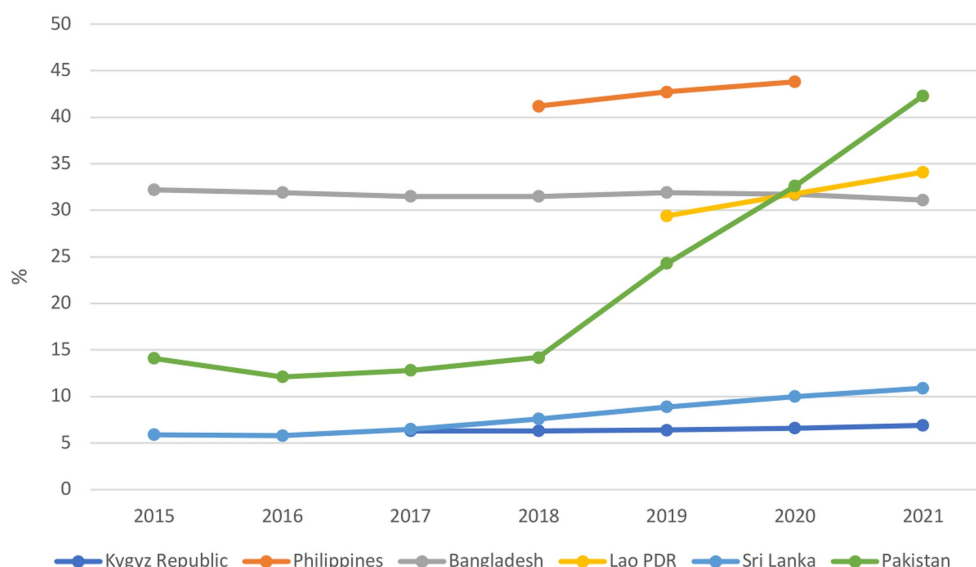


FIGURE 9

Percent of the population experiencing moderate or severe food insecurity.

most dramatic increase in food insecurity, from 14.2% in 2018 to 42.3% in 2021 in Pakistan (Figure 9). Similarly, there was an increase in the percentage of the population unable to afford a healthy diet from 2019 to the crisis period, with the exception of Bangladesh, where a declining trend was maintained (Figure I in Appendix B).

In order to support the findings on food security, we also examined the cost of diet. For all countries with available data, again with the exception of Bangladesh, there were greater increases in the cost of a nutritious diet compared to an energy-only diet. For Lao PDR, Sri Lanka and the Philippines, significant increases in the median cost of a nutritious diet were observed. For example, the median cost of a nutritious diet in Sri Lanka is nearly 300 percent higher compared to an energy-only diet (Figures J,K in Appendix B).

The analysis of percent change in FCS from the baseline point (2019) for Bangladesh, the Kyrgyz Republic, and Pakistan, showed that, in each of these three countries, the median acceptable FCS ($FCS > 42$) increased from baseline over the course of the crisis (Figure 10). For Pakistan, overall food consumption scores significantly improved in crisis year 2020 before worsening slightly in 2021 and 2022, but remaining above pre-crisis levels, with more households moving from acceptable to borderline ($FCS = 28.001-42$) scores in 2021. Median acceptable FCS decreased in Kyrgyz Republic and Bangladesh in crisis year 2020 before rising again. However, borderline FCS increased from the baseline in Bangladesh and the Kyrgyz Republic over the course of the crisis, spiking in 2020 then lowering, but remaining above the baseline in 2021 and 2022. Poor FCS ($FCS \leq 28$) went down in Bangladesh and Pakistan over the course of the crisis, while rising in the Kyrgyz Republic.

3.5 Model predictive power

Lao PDR had both the lowest total resilience capacity and lowest longer term resilience outcomes scores. This trend was also evident for two bottom-ranked countries, Pakistan and Bangladesh. Sri Lanka

and Philippines had the highest combined scores for total resilience capacities and agrofood diversity pre-crisis, and the second and third highest scores for longer-term resilience outcomes, respectively. Kyrgyz Republic somewhat buckled the trend with only the third highest resilience capacity score, but by far the highest longer-term resilience outcome score (Table 3).

4 Discussion

The unfolding global polycrisis has revealed a web of vulnerabilities within food systems and the findings of this study provide valuable insights into the diverse challenges and resilience capacities within each of the six countries - Bangladesh, Kyrgyz Republic, Lao PDR, Pakistan, Philippines, and Sri Lanka. The analysis of resilience capacities and agro- and food-diversity revealed varying growth rates. For resilience outcomes, the study revealed fluctuations in national food price inflation patterns, rice price anomalies, and the percentage of the population unable to afford a healthy diet across the countries. The findings underscored the challenges and adaptive capabilities within each country, shaped by economic, political, agricultural, and food affordability dynamics contributing to the long-term resilience of their food systems.

Despite differences in the set of challenges faced by the selected countries, there were some regional commonalities which are important for understanding and addressing food system resilience. The first characteristic is the Asia-Pacific region's extreme susceptibility to climate events brought about by climate change. The World Risk Index, which ranks countries based on their vulnerability to extreme weather events, lists seven Asia-Pacific countries among the top 10 countries with the highest risk (22). This expected increased frequency of climate-related events, including floods, landslides, droughts, and storms poses a severe test to the resilience of each country's food system, leading to disruptions in food supply chains, transportation, food price volatility and compromised food security as well as changes

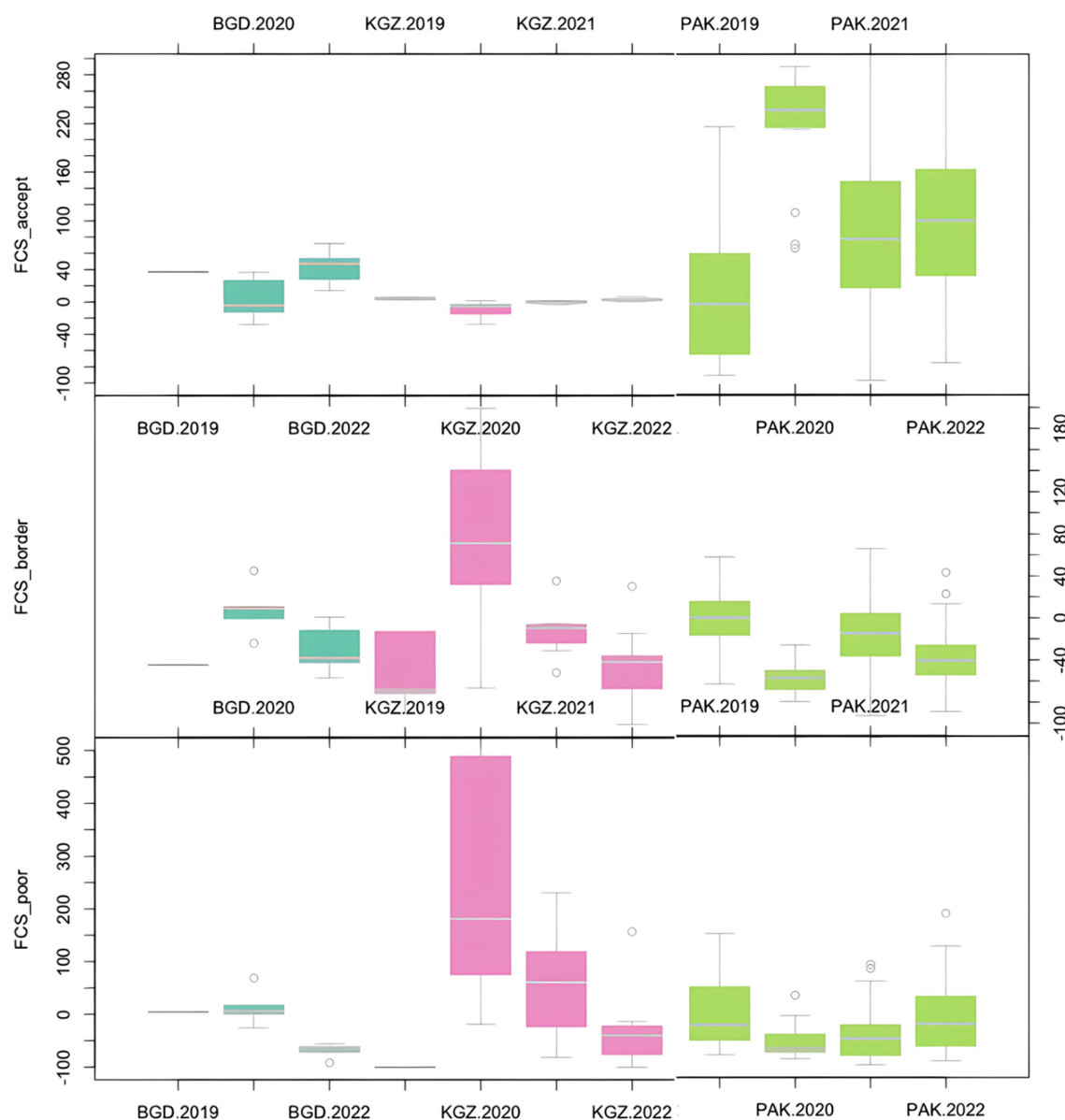


FIGURE 10

Percent change in household food consumption scores for three countries (baseline to 2022). BGD, Bangladesh; KGZ, Kyrgyz Republic; PAK, Pakistan. FCS_accept: households with acceptable Food Consumption Score (>42); FCS_border: households with borderline Food Consumption Score (28.001–42); FCS_poor: households with poor Food Consumption Score (≤ 28).

in yield, biomass, food composition, and nutritional quality, directly influencing human nutrition and health (23).

The second characteristic is the region's reliance on imports for much of its food supply. Most countries in the region are net food importers, often from the Ukraine, Russia, or both, leaving them "highly exposed" to rising global food prices (24). The third is the rapid and unprecedented urbanization taking place, referred to as "the defining megatrend" in the region (25), with nearly 55% of the region's population expected to live in urban areas by 2030 (26).

Our comparison of total scores for resilience capacities pre-crisis and total scores for long-term resilience outcomes measured in 2022 showed a tendency for countries with a higher total resilience capacity score at the outset of the polycrisis to also be the countries with a higher score for long-term resilience

outcomes. In other words, countries with higher total resilience capacities exhibited more desirable long-term resilience outcomes compared with countries with lower resilience capacities. Regarding resilience capacities and agro-food-diversity, food production increased from the pre-crisis starting point at a more accelerated pace than previous years in the majority of countries, demonstrated considerable strength in coping with successive shocks. This finding aligns with a study conducted by Dixon et al. (27) on the response and resilience of Asian agri-food systems to COVID-19. Their research highlighted the overall resilience of smallholder Asian farming food systems, which constitute a significant portion of the agricultural workforce in Asia (28), during the pandemic. Rural areas, especially in the countries targeted in our study, exhibited greater resilience due to lower

TABLE 3 Total scores for resilience capacities and agro- and food diversity, and long-term resilience outcomes for each of the six countries.

	Resilience capacities and agro- and food diversity*	Long-term resilience outcomes**
Sri Lanka	0.64	0.58
Philippines	0.64	0.53
Kyrgyz Republic	0.58	0.67
Bangladesh	0.57	0.50
Pakistan	0.56	0.44
Lao PDR	0.37	0.43

*Calculated for the following indicators: Crop production index, Fertilizer consumption, Livestock production index, Food import, NCD-protect, Mobile Cellular subscription, and Social capital index. **Calculated for the following indicators: Food Price Inflation, Food Price Anomalies (IFPA), by type of product (Rice), Food Price Anomalies (IFPA), by type of product (Wheat), Food supply variability, % population experiencing moderate or severe food insecurity, % population who cannot afford a healthy diet.

population densities, resulting in slower coronavirus transmission compared to urban areas. These countries showed resilience, with smallholder farms being relatively diversified, maintaining significant self-sufficiency (though declining), and having access to local markets for various farm and household needs, except during periods of obligatory closure, lockdown, or supply chain disruption.

Regarding long-term resilience outcomes, no country was immune from substantial food price inflation during the crisis period, reaching historic highs. A link between disruption in food supply caused by COVID-19 and food price inflation has been documented by others (29). Unlike previous major food price spikes in 2007–2008 and 2010–2012, this time, inflation was correlated with the depreciation of countries' currencies against the US dollar (30). The volatility of food prices was also evident in the observed price anomalies for rice, the most important staple food in Asia, across all countries. Food security indicators worsened proportionally from pre-crisis to the crisis period, i.e., countries with the highest pre-crisis food insecurity still experienced the highest food insecurity in the crisis period. Several reasons for the increase in food insecurity in the region have been documented, including COVID-19 leading to disruptions in national and international food supply chains, affecting the availability and accessibility of food items (31, 32). Furthermore, lockdowns resulted in immediate job losses, causing a reduction in household income (33), and the ramifications of the war in Ukraine, coupled with the rapid acceleration of food inflation, further exacerbated household food insecurity, reducing purchasing power (34). As a result, households scaled up their own-food production and foraging activities, reduced their food consumption, or shifted to cheaper foods, potentially resulting in inadequate nutritional intake. However, it is important to note that our resilience outcome data only extended to 2021, reflecting only the impact of the shock caused by COVID-19 and not the war in Ukraine which began in 2022.

Looking beyond regional characteristics and the overall association between resilience capacities and long-term resilience outcomes, the selected countries handled the impacts of the shocks (Covid-19 and the war in Ukraine) differently. This was influenced by their unique food system contexts before the onset of the shocks, as well as their internal economic and political situation.

Lao PDR, consistently exhibiting the lowest scores in resilience capacities and agro- and food diversity, as also recorded the lowest

score in long-term resilience outcomes. Despite fluctuations in recent years, it consistently had the lowest crop production index in the years preceding the crisis among the six countries. This negative trend can be attributed to the country's predominantly traditional and less productive agricultural practices (35), as well as its high vulnerability to climate-related hazards, particularly floods and droughts (36). In an already weak food system heavily reliant on agriculture, especially for rural communities, the recent shocks have further deteriorated resilience outcomes and increased food insecurity, which was already one of the highest among the countries.

Over the years, Pakistan has faced drought emergencies, resulting in severe water shortages that reduced irrigated land and crop production (37). This contributed to a low score in agro- and food diversity capacities. The country's food system also exhibits high volatility, especially in the unstable price of wheat, exacerbated by the drop in grain exports due to the war in Ukraine (38). Limited food storage capacity at household and governmental levels further weakens resilience, impacting the purchasing power and food access for the population (39). Even before the crisis, a significant proportion of the population struggled to afford a healthy diet, worsening in 2020 and making Pakistan face the worst food security outcomes among the targeted countries.

Bangladesh showed high scores for crop production and fertilizer consumption, yet low scores for livestock production, infrastructure, and social capital. In comparison to other countries where food supply variability received the lowest score, Bangladesh maintained constant values. This suggests the food system's ability to sustain constant variability in food supply in the face of shocks. Notably, Bangladesh is the only country where a decrease in the percentage of the population unable to afford a healthy diet was observed. An IFPRI study (40) reported a reduction in food insecurity to pre-pandemic levels, possibly attributed to the relaxation of COVID-19 restrictions and subsequently resumption of job activities.

Although the Kyrgyz Republic did not exhibit the highest resilience capacity score, mainly due to its much lower fertilizer consumption compared to other countries, it showed the highest long-term resilience outcome score. This was mainly thanks to the proportion of the population experiencing moderate or severe food insecurity, which has remained constant and at a low level, even during crisis periods. Nevertheless, these numbers face increasing threats from growing vulnerabilities to substantial

shocks and stress due to anticipated climate change (41). The reliance on domestic water supply from glaciers and snowmelt for agriculture, coupled with significant water losses from aging infrastructure, poses a significant concern for the country's food system (42).

The Philippines, standing out with the highest scores in resilience capacities alongside Sri Lanka, demonstrates high capacities linked to infrastructure and social capital, despite challenges such as low livestock production both before and during the crisis period. This challenge is attributed to the impact of epidemics such as avian flu and swine flu on food systems, leading to shortages of key food items (43). Interestingly, despite large variations in food inflation experienced by all countries, the Philippines was the least affected. However, it recorded the highest number of food-insecure people, particularly in Quezon City, emphasizing the significant challenges posed by rapid urbanization on the city's food system during a crisis, as revealed by a study conducted by Auma et al. (44).

Sri Lanka demonstrated generally high capacities in agro- and food supply diversity, as well as in infrastructure and social capital. However, the country received the lowest score for food inflation due to skyrocketing food prices, significantly impacting the population's purchasing power and access to food (45). According to a FAO report, factors contributing to the increased prices include low market availability, high production and transport costs, and disruptions in marketing activities due to severe fuel shortages (46). An additional factor influencing the heightened prices was the government-imposed ban on chemical fertilizer imports in April 2021, leading to a substantial reduction in rice harvests and subsequently driving up food prices (47). Nevertheless, Sri Lanka still exhibited the lowest number of people who could not afford a healthy diet compared to other countries, indicating a certain resilience in its food system.

This study has several important strengths. Firstly, it employed a conceptual model that provided a comprehensive assessment of food system resilience across six diverse countries. The model considered various dimensions and interrelated factors influencing food security and nutrition, providing a holistic view of the complex dynamics within each country's food system at the national level. The inclusion of interviews with representatives from WFP country offices was another strength, enabling us to contextualize the data extracted from global data sources and gain deeper insights into the food systems of each targeted country. Additionally, we could access unpublished information on food security and food resilience, offering an idea of what to expect in the near future in terms of food system resilience indicators. Furthermore, transformation of food trade data was conducted to examine the data through nutritional lenses. This approach allows us not only to investigate trends in food imports and assess how they have been affected by the crisis but also to distinguish the impact on healthy food and foods whose consumption should be limited.

Certain limitations should also be considered when interpreting our findings. Utilizing national level data does not capture the nuanced disparities and vulnerabilities faced by specific population segments, particularly lower-income households, minority groups, displaced persons, women and

children, who are likely to be disproportionately affected by the polycrisis. This limitation hinders a comprehensive understanding of how these inequalities affect resilience and adaptive capacities within food systems and points to a need for more localized and granular data in order to effectively target those most in need. Additionally, annual averages might mask stronger fluctuations in data that some indicators might have experienced during the year, and which could be captured with more frequently collected data. There were also substantial data gaps over the study period, especially for 2022 and 2023, meaning that the trends of some indicators may not have captured the effects of the war in Ukraine that started in 2022. This hampered the ability to provide an accurate assessment of the ongoing crisis's evolving nature and full effects on food systems. Furthermore, for indicators related to food security, for which data were supplied by the WFP, data collection methodologies and sampling methods vary among countries. In some instances, data were only collected from selected provinces in a country. Therefore, the presented results may not be wholly representative of the entire country. Finally, the conceptual model does not fully encapsulate the temporal dynamics of the crisis, as evolving impacts might not be fully captured in the reviewed data. Understanding the long-term effects of the crisis on food systems is challenging within the study's current scope.

4.1 Recommendations for future research

4.2 Resilience assessment in food systems

Research should delve into identifying which indicators prove most descriptive and useful across different levels and components of the food system and identify the minimum set of indicators that can be used to measure the entire food systems continuum (13, 48). These should be relevant for and applicable to diverse food systems at both national and subnational levels. Understanding the determinants of resilience is equally crucial, prompting an investigation into the factors that contribute to variations in resilience. This multi-dimensional analysis, encompassing socio-economic, environmental, and institutional dimensions, can provide a nuanced comprehension of the diverse pathways to food system resilience. Research should also consider the potential prolonged impact on food systems and their adaptive capacities beyond the immediate crisis phase.

4.3 Integration of climate change adaptation

To fortify food systems against the backdrop of climate change, it is imperative to gauge the extent of integration of adaptation measures (49, 50). Research should scrutinize the degree to which countries have embedded climate change adaptation strategies into their food systems and assess the impact of these measures during extreme weather events. This line of inquiry will shed light on the effectiveness of specific adaptation measures, offering valuable insights for refining strategies that enhance resilience.

4.4 Early intervention strategies

The anticipation and management of impending food system shocks represent a critical dimension of resilience (51). Research

endeavors should focus on identifying emerging trends or indicators that act as precursors to potential shocks. This exploration could pave the way for the development of predictive models, offering a proactive approach to early intervention strategies including anticipatory actions. Investigating the effectiveness of these models in real-world scenarios can significantly contribute to refining and tailoring strategies for timely responses to imminent challenges.

5 Conclusion

This study on the resilience of food systems in six Asia-Pacific countries amid global crises highlights the complex challenges posed by COVID-19, geopolitical conflicts, and climate change. It reveals disparities in resilience across countries, shaped by economic, political, and agricultural factors. The paper underscores the need for adaptive governance, targeted policy interventions, and transformative changes in food system management. The findings advocate for future research on resilience indicators, climate change adaptation, and early intervention strategies to strengthen food systems against global challenges.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Author contributions

CF: Writing – original draft, Writing – review & editing. CC: Formal analysis, Writing – review & editing. EW: Writing – original draft. KS: Writing – review & editing. MM: Writing – review & editing. DC: Formal analysis, Writing – review & editing. AS: Supervision, Writing – review & editing. JK: Supervision, Writing – review & editing. SM: Supervision, Writing – review & editing. SG: Supervision, Writing – original draft.

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Conflict of interest

CF, CC, EW, KS, MM, DC, and SG were employed by Nutrition Research, Dikoda Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2024.1347186/full#supplementary-material>

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State school catering in Italy during the COVID-19 pandemic: a qualitative study

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The complex value of school meals for children and families is well documented. In Italy, school cafeterias have been an instrument of social policy since the end of the Second World War. Thereafter, school cafeterias have acquired several functions in the areas of children's health and wellbeing, education, social inclusion, support to local and quality agriculture, and environmental sustainability. In particular, the goal of a nutritious and balanced diet has been emphasized in recent decades, since malnutrition and food insecurity have been increasing in Italian society. During the pandemic, Italy was the first European country to implement a nationwide lockdown and one of the high-income countries where schools closed for the longest period. In this work, we use in-depth interviews with representatives of the school catering service, both from the major catering companies and the biggest municipalities, to analyze what happened in the management of the Italian school catering service during the pandemic crisis. In addition, a review of public recommendations issued during the pandemic has made it possible to analyze their compliance with the state guidelines for school catering and food education. The results highlight how the system reacted extremely slowly to the crisis and how the measures taken led to a deterioration of the value that has always been attributed to state school cafeterias, especially in terms of children's food security and environmental sustainability.

KEYWORDS

school cafeterias, service management, COVID-19 pandemic, school closures, food security, Italy

Introduction

The value of school meals

Extensive literature has shown that school meals play an important role in addressing major food challenges—such as eradication of hunger [Tikkanen and Urho, 2009; Jomaa et al., 2011; Robert and Weaver-Hightower, 2011; World Food Program (WFP), 2013, 2015; De Schutter, 2014; Kleine and Brightwell, 2015; World Food Programme (WFP), 2020a], reduction of obesity and other food-related diseases [Gleason and Sutor, 2003; Pyle et al., 2006; Greenhalgh et al., 2007; Harper and Wells, 2007; Kristjansson et al., 2007; Jaime and Lock, 2009; Pike and Colquhoun, 2009; Raulio et al., 2010; Capacci et al., 2012; Ashe and Sonnino, 2013; Chriqui et al., 2014; Chang and Jung, 2017; United Nations System Standing Committee on Nutrition (UNSCN), 2017; Baltag et al., 2022], development of local economies, ecological sustainability and ethics of food systems

[Morgan, 2008; Morgan and Sonnino, 2008; Sumberg and Sabates-Wheeler, 2011; United States Department of Agriculture (USDA), 2015; Swensson, 2019; Swensson and Tartanac, 2020], and education of children on food-related issues (Winne, 2005; Morgan and Sonnino, 2006; Harper and Wells, 2007; Harper et al., 2008; Weaver-Hightower, 2011; Benn and Carlsson, 2014; Rice and Rud, 2018; Lombardi and Costantino, 2020)—and bring about a mix of social, economic, and environmental outcomes at the same time (McCrudden, 2004; Di Chiro, 2008; Fanzo et al., 2013; Van Lancker, 2013; Filippini et al., 2014; De Schutter, 2015; Fitch and Santo, 2016; Oncini and Guetto, 2017; Oostindjer et al., 2017; Gaddis and Coplen, 2018; Bundy, 2022).

School catering in Italy before the pandemic

In Italy, school catering has a rich history, as school cafeterias have been an instrument of social policy since the end of the Second World War, when they served to combat widespread malnutrition among the population, facilitating access for the poorest social classes to a healthy and complete diet (Helstosky, 2006). Since then, school cafeterias have acquired several values and functions in the areas of children's health and wellbeing, education, social inclusion, and environmental sustainability [Ruffolo, 2001; Morgan and Sonnino, 2006, 2008; Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR), 2011, 2015]. In particular, the goal of a nutritious and balanced diet has been emphasized in recent decades, since malnutrition and food insecurity have been increasing in Italian society. Indeed, according to the national school-based monitoring system called "Eye on Health" (OKkio alla SALUTE), 30% of Italian children are suffering from obesity and being overweight, with higher values for children from families in more disadvantaged socio-economic conditions (Nardone and Spinelli, 2020). Italy has one of the highest child poverty rates in Europe and it is 31 out of 44 among the OECD countries for this indicator [Organisation for Economic Co-operation and Development (OECD), 2021]. The Italian National Institute of Statistics (ISTAT, 2021) highlights that 10% of Italian families cannot afford an adequate meal every 2 days. Sixteen percent of Italian children are living in poverty, deprived of basic necessities, including three meals per day, fresh fruits and vegetables every day, and at least one meal a day with a rich protein source (UNICEF, 2012). According to ActionAid (2020), Italian children and women are those most exposed to food poverty, characterized by both an insufficient amount of food and an inadequate diet. COVID-19 lockdown significantly accentuated the problem, since most of the families interviewed in the ActionAid survey suffered from severe food insecurity during the two first months of the pandemic, i.e., repeatedly skipping meals due to lack of sufficient food. Farello et al. (2022) observed an increase in the consumption of high-calorie snack food and obesity during the pandemic among Italian children and adolescents, while De Lorenzo et al. (2022) highlighted that the link between obesity and the COVID-19 pandemic followed the link between the social inequalities and nutritional disparities already proven in Italian society.

School catering is a service provided in nursery, infant, as well as primary and lower secondary schools, with a nature of local public service on individual demand. The local authority is therefore not obliged to set up such a service, but can do so within the scope of its general competence, taking on and managing the production of goods and activities aimed at achieving social goals and promoting the economic and civil development of local communities (Article 112 of Italian Legislative Decree 267/2000). When it decides to establish such a system, the institution undertakes to provide the service to all those who request it, establishing the share of the cost to be paid by users, which may be means-tested, and the share to be paid by the municipality (Articles 42 and 43 of Italian Presidential Decree 616/1977, as amended). The school catering service is therefore managed by municipalities, which are responsible for organizing the service in case of full-time schooling. Families pay for school meals at varying rates according to their income. For the poorest families, monitored by social services in the municipality, school meals are free. The municipalities define the characteristics of the service, in compliance with the Italian national guidelines for school nutrition issued by the Ministry of Health (Ministero della Salute, 2010, 2018, 2021), which regulate hygienic, sanitary, and nutritional aspects, as well as aspects surrounding food behavior, culture, and food waste prevention. Municipalities can deliver the service directly or, more commonly, entrust it to catering companies, which prepare meals in kitchens within schools or outside (centralized). Meals are consumed in school cafeterias. In the 2020/2021 school year, 32.9% of state school buildings were equipped with cafeterias in Italy, with a very high variability, i.e., in Piedmont the percentage reaches 62.4, while in Sicily it drops to 10.2 (Con i Bambini, 2023). About 1.4 million students eat at school, equal to 17% of the total population enrolled, but the use of school cafeterias varies across regions, i.e., almost all students access food through the cafeterias in northern regions, while access is much lower in southern regions, such as Sicily, Calabria, and Campania [Global Child Nutrition Foundation (GCNF), 2020]. Meals take place as a class group, with the children eating together with their teachers and the meal time is to all intents and purposes school time and not a break from educational activities, for both the children and the teachers. The service includes a mid-morning snack and lunch, commonly a carbohydrate-based first course, a protein-based second course accompanied by a side dish of raw or cooked vegetables, fruit or dessert, and bread.

The service is monitored both by municipalities, through the local health authorities, and Cafeteria Committees (CMs). CMs are a representative body of parents and teachers that monitor the service and have a say in public food procurement decisions (i.e., recipes, suppliers, etc.) (Galli et al., 2014). In support of the educational function of the school meal, school food education (SFE) initiatives are encouraged by the Italian Ministry of Education through the Guidelines for Food Education [Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR), 2011]. In Italy, 81% of schools organize food education courses and 63% offer extra-curricular activities regarding food (Ministero della Salute, 2021).

Moreover, a 1999 law [Finance Law no. 488, Art. 59(4)] provides for the daily use in school and hospital cafeterias of organic, typical, and traditional products, protected by designations

of origin. Further environmental sustainability requirements for school meals were introduced with the Minimum Environmental Criteria regulated by the Italian Ministry for the Environment, Land and Sea with Decree No. 65 of 2020. According to [Morgan and Sonnino \(2008, p. 65\)](#), the Italian system is “revolutionary” in its ability to support a sustainable, high-quality agri-food supply chain.

Therefore, the Italian school catering service has acquired numerous social values in the sphere of nutrition, health and wellbeing, education, and sustainability.

The impact of COVID-19 school closures on children's nutrition

By March 2020, 171 countries had closed their schools in response to the COVID-19 pandemic and 336 million children, more than 90% of the world's enrolled children, were left out of school ([UNESCO, 2020](#)). The closures occurred in different ways and durations around the world in 2020 and 2021 ([UNICEF, 2021](#)). Quite early concern arose that children were not only missing education, but that there were also consequences due to the loss of food services provided by schools [[World Food Programme \(WFP\), 2020a](#); [World Food Programme \(WFP\), FAO, and UNICEF, 2020](#); [Borkowski et al., 2021](#)]. Evidence from previous school closures shows that missed school meals can cause significant consequences in children's health and wellbeing in the short and medium term. Children tend to gain weight and be more at risk of malnutrition and undernutrition during summer breaks ([Franckle et al., 2014](#); [Huang et al., 2015](#); [Wang et al., 2015](#); [von Hippel and Workman, 2016](#)), while eating school meals daily is associated with healthier dietary intakes ([Au et al., 2018](#); [Decataldo and Brunella, 2018](#); [Marcotrigiano et al., 2021](#)). According to several authors [[Rundle et al., 2020](#); [Stavridou et al., 2021](#); [De Lorenzo et al., 2022](#); [Farello et al., 2022](#); [World Health Organization \(WHO\), 2022](#)], the pandemic exacerbated the childhood “obesity epidemic” ([Gard and Wright, 2005](#)) and increased the social disparity in obesity risk.

Global responses

While school meals were not possible during COVID-19 school closures, many countries and international organizations adapted their traditional school catering programs, providing home delivered meals, cash transfers, or food vouchers ([Borkowski et al., 2021](#)). World Food Programme data [[World Food Programme \(WFP\), 2020a,b,c](#)] indicate that take-home food supplies were the most common response alongside unconditional cash transfers and multiple responses both at state and decentralized levels.

Among high-income countries, several responded with alternatives to school meals. In the United States (US), through the national program to combat food poverty for children and young people (the US Department of Agriculture National School Lunch Program and School Breakfast Program), various strategies were developed to bring meals to children's homes during the pandemic. As [Kinsey et al. \(2020\)](#) explain, the actions were based on flexibility and included the option to: collect meals in various parts of the

city, as well as receiving them at home; collect multiple meals for the same day or for multiple days at once; have people other than the students pick up meals; collect food vouchers instead of meals; choose and book meals online; and temporarily simplify the bureaucratic aspects associated with the distribution of meals. In some areas of the country, it was also possible to extend the supply of meals to the whole week and not just to school days, and to all children and young people from 0 to 18 years of age (and up to 26 years of age for those with disabilities), even those not enrolled in school, as well as distributing free meals also to the adults of the family (*ibidem*). These strategies involved a huge financial, organizational, and logistical effort from school catering authorities, but school meals continued to reach the children, while the staff employed in the sector remained in service and, in some cases, saw their roles enhanced, either directly or through partnerships with the private and voluntary sectors (*ibidem*).

In the United Kingdom (UK), a national voucher scheme was implemented and families with children eligible for free school meals were able to claim weekly shopping vouchers worth £105 to spend at supermarkets while schools were closed ([UK Department for Education, 2020a,b](#)). Following on from this experience, the City of London has decided to provide emergency funding to distribute free meals during school holidays to combat hunger, starting with the Easter holidays in 2023 ([London City Hall, 2023](#)). During remote learning, lunches were provided to children through food packs in Estonia, prepared takeaway meals in Finland, and lunch boxes in Sweden ([Ala-Karvia et al., 2022](#)). In Latvia, several alternatives were provided, such as food packs, gift cards or vouchers, transfer of money into families' bank accounts, takeaway lunches, or lunches delivered at home ([Beitane et al., 2021](#)). Food packs were, however, the simplest and safest form of state support for families with school-aged children ([Beitane and Iriste, 2022](#)). Students in Ireland were sent home packages with fresh foods, including bread, eggs, fruit, and yogurt; in Hungary, the provision of meals to children continued through meals delivered by the same kitchens used for cooking school meals before the pandemic; in Spain, families with children were entitled to cash transfers or direct food distribution during school closures [[World Food Programme \(WFP\), 2020b,c](#); [Global Child Nutrition Foundation \(GCNF\), 2022](#)].

As we have seen in this paragraph, there is a significant body of literature focusing on the COVID-19 pandemic, which has observed the feasibility of preserving the school catering service even during crises to safeguard its social function. This recognition of the social value of school meals carries important implications for the implementation of future post-pandemic social policies.

What happened in Italy?

As UNICEF reports ([Mascheroni et al., 2021](#)), Italy was the first country in Europe to implement a nationwide lockdown. Schools and universities began to close in late February 2020, starting with the north of Italy (Lombardy, Emilia-Romagna, Liguria, Piedmont, Veneto, and Friuli Venezia Giulia). By March 10, 2020, the Italian government extended lockdown measures to all regions in the country. Children and their families lived in almost complete

isolation for almost 2 months until May 3, 2020, and schools remained closed until September. In 2020, Italian students missed 65 days of regular school due to COVID-19 lockdown measures, compared to an average of 27 missed days among high-income countries worldwide (*ibidem*). Further periods of school closure with online lessons occurred in the 2020/2021 and 2021/2022 school years. The duration of the interruption varied according to the spread of the virus across the region and school order, causing a general large discontinuity of school attendance. School catering was suspended whenever schools were closed. Prevention measures were implemented to regulate the school catering system when schools reopened.

Objectives

The present work aims to analyze the measures taken to face the COVID-19 pandemic in the Italian school catering system and their impact on the social values of school cafeterias. As far as we know, several studies (e.g., [De Lorenzo et al., 2022](#); [Farello et al., 2022](#)) explored the changes in the Italian children's dietary habits that occurred at home during the COVID-19 pandemic, but only [Barocco et al. \(2021\)](#) looked at changes in school meals. However, they limited their investigation to the changes in the nutritional quality of school meals and to the school cafeterias in the Province of Trieste. Therefore, there was a research gap on technical and organizational changes, and on their social consequences, in the school catering system, at national level. This study intends to fill this gap, by highlighting the unique perspective of school catering representatives who deeply know limits and possibilities of adaptations in the provision of school meals. The qualitative investigation of the perspectives of the managers of the service, together with the review of public guidelines issued during the pandemic, allow for reflection on what happened and what can be learned from the pandemic. In this contribution, we propose following and reconstructing the socio-material events of an action program, i.e., the implementation of COVID-19 prevention measures in the school catering system, and therefore participate as observers in the performative dynamics investigated. In theoretical terms, the reference is to the work of Callon, who highlighted the dynamics of translation ([Callon, 1984](#)) and performativity ([Callon, 2008](#)) that characterize each action program at the time of its implementation. The issue of performativity refers to the transformative dynamics that mutually involve the socio-material network in the implementation process. According to Callon, action programs are translated in practice through inevitable negotiations, reformulations, and transfers within the spatial and temporal contexts of the network of social and material entities that are involved and influenced. This perspective justifies a pragmatic analysis of the experience, by providing precise descriptions of the dynamics that characterize it and the elements and connections that perform it ([Callon and Latour, 1981](#)). In our analysis, we asked the school catering system managers to trace all the changes that have affected the service in all phases of the pandemic. The analysis aimed to identify the ways in which materiality (technologies and techniques), practices, and meanings translated the preventive program.

TABLE 1 Overview of interviews conducted.

Representatives of school food service		Other key informants
Catering businesses CAMST CIRFOOD Dussmann Serenissima	Municipalities Bologna Milan Naples Palermo Rome Turin	Officer of the Trieste department of prevention and public health Consultant for school food catering Director of a specialized magazine Caritas observatory officer President of Foodinsider Education office manager of the association of Italian municipalities

Materials and methods

The analysis was performed by combining public document examination and in-depth interviews to key informants. All the state documents relating to the management of the Italian school catering service during the pandemic were examined, i.e., the School Plan for the 2020/2021 school year adopted by Decree of the Ministry of Education No. 39 of June 26th, 2020, the School Plan for the 2021/2022 school year adopted by Decree of the Ministry of Education No. 32144 of July 27th, 2021, the Technical Document on containment measures in the school sector of the Scientific Technical Committee of the Civil Protection Department of May 28th, 2020. The guidelines of several regional authorities—those of the Emilia-Romagna region ([Regione Emilia Romagna, 2020](#)), those of the Municipality of Milan ([Città Metropolitana di Milano, 2020](#)), and those jointly defined between the Lazio region and the Municipality of Rome ([Regione Lazio, 2020](#))—and those of other relevant public institutions—the Italian Society of Hygiene, Preventive Medicine and Public Health [[Società Italiana di Igiene Medicina Preventiva e Sanità Pubblica \(SIIP\), 2020](#)—were also considered in the review of public indications.

Sixteen interviews were conducted with representatives of the school catering service from the major catering companies operating in Italy ([Edifis and Ristorando, 2023](#)) and the biggest Italian municipalities (i.e., Rome, Milan, Turin, Bologna, Naples, and Palermo), and other sector experts ([Table 1](#)). Municipalities and catering companies are the key players involved in the management of the school catering system. The former oversee the governance of the service, setting forth the rules that govern it (tender specifications), and evaluating its adherence to these established requirements. The latter source raw materials, prepare, and distribute meals in alignment with the contract's specifications. Despite their distinct roles, they are the primary experts on the functioning of the service. They do not constitute two management systems but rather two different perspectives on the same management system.

The catering companies were contacted via the email addresses available on the corporate websites, explaining the objectives of the research and asking to be put in contact with the managers of the school catering division. We proceeded in the same way with the municipalities. In a few cases it was necessary to solicit an answer by calling the telephone numbers available on the websites.

TABLE 2 Interview guide.

Research questions	Interview questions
What happened to the management of the school cafeteria service in the first phase of the pandemic, when schools were closed?	Has the service been suspended? Have the families' payments for school meals been stopped? Were there any initiatives to support poor families, who benefited from free or reduced rates school meals before the pandemic?
What happened to the management of the school cafeteria service in the second phase of the pandemic, when schools were open?	What were the main changes, i.e., organizational, logistic, economic, relational, in supplies, menus, or other?
Have the social values of the school catering service been safeguarded?	What has changed in the service after the pandemic? What could have been done differently or could be done in the future in dealing with similar situations? What are the lessons that have been learned, if any? In other high-income countries, including European ones, alternatives to school meals have been developed during the pandemic such as food packs, vouchers, take-away lunches or lunches delivered at home. In your opinion, would it have been possible to organize similar responses? What do you think about a service of home delivered meals for the children entitled for free or reduced rates school meals? What critical issues do you see with respect to this option: i.e., organizational, logistic, economic?

For the experts, the first interviewees were tracked down by examining online sector magazines and events, then others names were obtained by interviewing the first experts. The interviews were conducted between November and April 2023 by phone. We adopted a discursive approach (Rapley, 2007) and facilitated the discussion by using an interview guide (Table 2), which consists of a sequence of topics to be covered and a list of open questions to be followed (Kvale, 2007). The interview guide is deliberately spare because it only intends to guide the interviewees' narrations, encouraging unexpected issues to emerge. Thus, the interviewing approach assumes that the research participants have substantial experience of the study specific topics and that the researcher does not know all the pertinent questions to ask in advance. At the same time, this approach allows the researcher to add questions aimed to explore issues that arose in the first interviews or to proceed more quickly on topics that previous interviews have already saturated (Charmaz, 2014, p. 56–59).

The conversations were recorded, with the interviewees' permission, and transcribed. A single researcher performed the analysis. Grounded theory in its latest evolution (e.g., Charmaz, 2014; Corbin and Strauss, 2015) was used to develop an understanding and interpretation of the data collected. Grounded theory is an interpretive method used to systematically analyze qualitative materials and to generate concepts (*ibidem*). In our analysis, we used different categories to identify significant changes

in the organizational, logistic, economic, and regulatory aspects of the school catering service during the pandemic; the nature of roles and responsibilities of different actors and their relationships; significant processes and practices; and perceptions and views about social values of the school catering service. Therefore, in defining the relationships between categories and detailing their properties, we constructed an explanatory interpretation of the data collected that answered the research questions (i.e., what happened to the school catering service during the pandemic and what impact did the pandemic have on its social values). The whole process was managed by using a software for qualitative data analysis (MAXQDA Analytics Pro 24).

Results

During periods when schools were closed due to the pandemic, the school catering service was interrupted. The municipal authorities interviewed explain that the rates paid by families for school meals were suspended and those who had already paid the cost of the service in advance were reimbursed. Contracts between municipalities and catering companies were suspended as well. The interviewees acknowledge that, amidst the school closures, this is the only initiative that affected a service previously regarded as of great social significance.

When schools reopened, numerous changes affected the service. From the analysis of public documents, it emerges that the general guidelines to be followed to counter the pandemic were defined at central level (Italian Ministry of Education, based on the indications of the Technical-Scientific Committee of the Civil Protection Department) and included physical distancing of at least one meter, the obligation to wear masks for all school staff and for children aged 6 and over, the intensification of cleaning and sanitation operations of environments and equipment, the frequent ventilation of buildings, and the sanitation of hands with disinfectant products. In the 2021/22 school year, the obligation for COVID-19 green certification was added to these measures for all school staff. The use of school buildings was limited exclusively to conducting educational activities, including sports in the gym and the consumption of meals. Respecting the autonomy of the schools and the differences in the spaces available, it was left to the school administration, in agreement with the local government, to define solutions to implement physical distancing. For school meals, for example, measures were encouraged such as two or more shifts in the cafeteria, the use of alternative school buildings, or lunch boxes to be consumed in the classroom. A simplification of the menus was suggested in cases where the supply of foodstuffs was difficult. Finally, the use of single portions of food in individual trays and the use of disposable, compostable where possible, cutlery, glasses, and napkins were required. In the 2021/22 School Plan, the administration of meals was once again authorized in the usual forms without disposable tableware, but made of durable materials. All other precautionary measures remained in effect.

At the local level, with a collaborative project between municipalities, schools, and catering companies, the organizational and logistical procedures were developed which made it possible to implement the ministerial indications. One interviewee explains that "blanket" and "heroic" site inspections were carried out due

to the commitment they required, in order to verify the specific conditions and develop *ad hoc* solutions. Another interviewee explains that a customized plan was made for each municipality, through a lot of discussions. The manager of a catering company explains that “To rewrite the service, the experience that the catering companies had gained in care homes and hospital catering was useful, since these services had continued to function even during the lockdown. For example, we had experimented with a teamwork approach, i.e., in multifunctional teams that included cooks and other cafeteria operators and who had to remain isolated from the rest of the staff.” In many schools the same approach was used for children, divided into learning groups isolated from other children (so-called “bubbles”).

At an operational level, to respect the distance required by the measures to combat the pandemic, the cafeterias were no longer sufficient to accommodate all the school children, so a very common solution was to have lunch in the classroom or in other areas of the school, such as the gym, or lunch in the cafeteria over several shifts. “Each municipality behaved differently. Spaces outside the schools were also used, such as the auditorium. Of course, the adequacy of the spaces was checked by the local health authority,” says the manager of a catering company. All staff working in the cafeteria used personal protective equipment such as masks and gloves. Cleaning and sanitizing actions were intensified.

The transport and distribution of meals in classrooms required a simplification of the menus, with the temporary removal of liquid meals such as soups, and the use of disposable, lighter tableware.

All those precautions that avoided contact between children and operators as much as possible were preferred: single-portion foods, where possible in heat-sealed packages, water in plastic bottles instead of tap water in jugs, multi-ration trays, lunch boxes or a platter, i.e., a single plate on which there were first, second, and side dishes, as well as disposable tableware. According to one expert interviewed, the lunch box solution made it possible for children to eat only what they liked most, with negative consequences in terms of correct nutrient intake.

An expert explains that with the lengthening of the times between the preparation and distribution of meals and the need to keep the food always at the same temperature (above 65°C) all the time, the organoleptic characteristics of the meals worsened (for example, overcooked and dry pasta), with a consequent reduction in enjoyment, consumption, and nutritional intake. The greater use of meals prepared in cooking centers and then conveyed in isothermal containers instead of meals prepared in internal kitchens also led to a worsening of the organoleptic characteristics. According to an association that monitors the quality of school meals in Italian schools, this type of precautionary measure found no scientific basis in the documents on COVID-19 and food safety from the WHO, the European Center for Disease Prevention and Control, and the Italian National Health Institute (Istituto Superiore di Sanità). The risks of this option were the huge increase in waste (plastic and food), the loss of food fragrance, and the impoverishment of the nutritional value of the meal. “The flattening of the variety of menus—continues the interviewee—was another cause of the decline in the quality of school meals during the pandemic. In some situations, it came to just pasta, pizza, and cold cuts.”

On this point, the managers of catering companies disagree. Sometimes, there was difficulty in guaranteeing the expected foods, due to the lack of suppliers of foodstuffs and exceptions were requested from the municipalities to change the recipes set out in the contract, but the cases of deterioration in the quality of the food used were sporadic.

Monitoring by the municipal administration served to prevent changes in the organization of the service or in the recipes that were not necessary to guarantee health safety. Monitoring took place through internal staff (teachers and dieticians in the municipality). As explained by an interviewee, in the Friuli Venezia Giulia region, a survey was conducted by the public administration to verify the adherence of the service to the pre-pandemic specifications. The concern of the administrators was that there may be excessive and unjustified simplification of the menus or the use of disposable materials. The investigation made it possible to ascertain that the menus had resumed almost as they were before, without substantial changes.

One interviewee explains that the consumption of meals in the classroom had a negative impact on the socialization and psychophysical wellbeing of the children. In particular, it prevented a broader exchange with the entire school population and helped to communicate a sense of closure and abnormality to the children. An interviewee recounts that his catering company conducted a survey on the perception of school meal times by teachers. The results showed that for 47% of respondents it was a sad moment due to COVID-19 regulations (Osservatorio CIRFOOD District and Ipsos, 2022). At the same time, the classrooms were quieter than the cafeterias, allowing for higher quality communications. Noise in cafeterias is considered negative by 67% of teachers (*ibidem*).

All activities involving the presence of external personnel not strictly necessary, i.e., in addition to teachers and cafeteria operators, were suspended. All food education activities were interrupted, although some companies among those interviewed reported that they had prepared and recorded educational content that could be used online by teachers and children or delivered remotely by dietitians. Service quality control activities by CMs were also interrupted.

All participants agree in saying that the transport and distribution of meals in the classroom, the increase in shifts in the cafeteria, and the intensification of the cleaning and sanitization operations of spaces and equipment (e.g., tables and chairs) all required an increase in the working hours of the staff employed in cafeterias or the recruitment of new staff. New personnel were also necessary to deal with periods of illness and quarantine among personnel.

The volume of meals served changed continuously due to the quarantines to which all the children in the class were subjected in case of infection of individuals. A drop in attendance of about 30% is estimated by the interviewees. Meal booking systems via apps had already been used before the pandemic, but during the pandemic they became common practice.

The municipal authorities explain that the cost increases were supported by the municipal administrations, which paid the companies a supplement for the higher expenses due to the pandemic. Nonetheless, all catering companies said they had directly incurred extra costs due to the pandemic. They estimate

that costs increased by 25% and that so-called “COVID rebates” covered about 90% of the higher costs incurred by companies.

One interviewee explains that Government Decree No. 4 of 2022, the “*Sostegni-ter*” (Supports-*ter*), introduced the obligation to include price revision clauses in the tender documents in the event of cost increases due to emergency situations. These clauses were introduced in public tenders with regard to award procedures called after the entry into force of the decree and until December 31st, 2023. All the tenders called before this rule did not expressly provide for the possibility of revising the price because the clause was not mandatory. A revision of the public procurement code is currently being developed and in the published drafts it seems that the possibility of revising the price in emergencies is expressly laid down.

The Table 3 summarizes the changes that occurred during the pandemic with respect to the social values of the school catering service.

Why was an alternative to school meals not thought of during school closures?

The new organization of the service and the technical solutions introduced have led to a general deterioration of the social values recognized in school meals, as summarized in Table 3. In particular, the objective of the analysis was to understand the perception of the respondents regarding the role of the school meal in combating food insecurity, given that a significant number of articles and institutional reports, cited in the introduction, highlights the problem of food poverty in Italy, especially among children. With respect to this issue, municipal officials explain that in addition to the school catering service, the municipalities are also responsible for the service of providing home meals to people in particular situations of need, especially the elderly, the sick, those unable to leave the house, and those without aid or economic means. Generally, the service is managed under the same contract as school catering and therefore by the same catering companies. This service continued throughout the pandemic. The extension of home meals to school children, at least to those entitled to free or reduced rate meals, was not taken into consideration. There were sporadic initiatives for low-income families thanks to the sensitivity of certain local administrations, but mostly the tools used to support low-income families were food packages and vouchers for the purchase of food and other basic necessities. This aid was managed by the Civil Protection Department, charitable associations, and social services in the municipalities, but in a way that was disconnected from the school catering system. One interviewee explains that:

“During the first few months of the pandemic, there was a large amount of aid to families in need of food and other basic necessities. Food donations from food industries and catering companies were huge. Restaurants were closed and had full fridges. The food that arrived was of excellent quality and even in excessive quantities compared to the requests, and was distributed in droves. Families in a state of hardship were taken care of by charitable associations which coordinated with

TABLE 3 Summary of what happened during the pandemic compared to the social values of school catering.

Expected social values of school catering	What happened during COVID 19 pandemic
Nutritional and balanced diet	Simplification of menus with impoverishment of the variety of foods Deterioration of organoleptic quality and liking of meals, with consequent reduction in consumption and nutritional intake Use of foods of poor nutritional quality Quality control activity suspended
Food security	No initiative planned for children entitled to free or reduced rate school meals
Food education	Activities conducted by external personnel prohibited
Environmental sustainability	Increased waste of plastic and other packaging materials Increased food waste
Conviviality, social relations, and recreation	Eating in different environments and ways contributed to increase the sense of abnormality of the situation perceived by the children Eating in classrooms was quiet, but did not facilitate the necessary interruption between lessons and lunchbreaks Reduction of relationships with schoolmates

social services in the municipalities and with the food bank. With the persistence of the pandemic, there was a general impoverishment of families and a decrease in both quantity and quality of aid. The foodstuffs distributed returned to the pre-pandemic ones, above all canned goods, long-life, of modest quality. Adults alone and in difficulty were able to access charity cafeterias, but families with children did not go and therefore had to rely on food packages which were inadequate to support proper nutrition for children. There was, for example, no fresh food in food packages. Some charitable associations dealt with the distribution of unsold fresh food from supermarkets, but these initiatives were sporadic because they require more complex logistics and organization than charitable associations, based on the work of volunteers, are unable to ensure. Vouchers were rarely used because they did not allow control over what was purchased—there were cases of people buying alcohol with vouchers—but they would be very useful for families in situations of transient poverty. If linked to the possibility of purchasing only in neighborhood businesses, they would at the same time support small shops in difficulty due to the pandemic, and also prevent food desert situations in many urban areas, especially marginal ones. There was, however, no structural institutional coordination system that allowed for the connection of assistance services for poor families, school catering, and charitable associations. . .”

The need for an organic aid project for the poorest families, which also included the school catering system, also appeared possible to another interviewee, who suggested that, in order to

support families living in poverty, instead of home meals, catering companies could provide the option to buy food products at their company outlets, at controlled prices, due to the fact that the catering company purchases food products in large quantities.

All respondents agreed that it would have been very difficult to organize a home meal preparation and distribution service. While technically possible, the cost of providing school meals at home is considered excessive. One interviewee specifies that “the costs of home delivery are higher than a traditional service, they can vary according to the distance and the number of deliveries to be made, indicatively an increase of 30%–40% must be considered.” Another interviewee points out that in an ordinary situation the cost of home meals could be even lower than school ones because it does not include the cost of distribution in the cafeteria, but that in times such as the current ones of increasing fuel costs, the cost of logistics would become “exorbitant” and significantly affect the cost of a meal brought home. An option of this type would also require an investment in means of transportation because the transportation used to supply to companies would not be sufficient.

This perception of the economic unsustainability of home delivered meals, widespread among service managers and many experts, is most likely influenced by the current situation of economic difficulty in the sector due to the Russian-Ukrainian conflict, which has “brought the sector to its knees.” Since the beginning of the war, in fact, the continuity of supplies of foodstuffs has been compromised and their prices have increased, as have those of energy and transport. The agri-food industry, including distribution and catering, has experienced a sharp increase in production costs.

The distribution of home delivered meals to large numbers is not considered sustainable, including from a technical and organizational point of view. “Another problem with home delivered meals is that, if hot, they must be prepared and then kept at precise temperatures. This requires further organization and adequate means of transportation.” One company among those interviewed has set up a system for workers who work from home. They can book their lunch online and then pick it up at a vending machine, like the lockers used by Amazon for parcels, but refrigerated. The meal is then heated in a microwave oven. This system could also have been developed for school catering, by activating contracts with families. The important aspect to take into consideration for this method of supplying meals is that users must be correctly informed on how to store meals, if not consumed immediately after collection. Otherwise, meals may risk not being compliant from a hygienic and sanitary point of view. Safety procedures must also be defined in the home management of the meal.

A catering company sees opportunities for home delivery for the middle to high school segment of the school population. One manager explains that:

“Very often these kids eat lunch at home alone, while their parents are at work, because they are already old enough, but there is no information on the quality of their meal and we can imagine that it is not good. This population of children and young people is completely excluded from the provision of school meals and food education initiatives. Then, later, if they go to university, they will use the university cafeterias.

There is a gap in the service for children between the ages of 11 and 19 and we could imagine a home delivery service by school catering companies, capable of providing meals that are certainly healthier and more balanced than those that can come from commercial catering and from the rapidly expanding food delivery system.”

According to some interviewees, parents themselves would not have appreciated the home delivered meal service, while they would have gladly accepted meal vouchers. “Already [parents] are complaining that school meals are not good, let alone if we deliver them to home!”. Another interviewee adds that the quality of school meals is not perceived by families, so food education would also be necessary for parents in order to inform them and encourage them to participate in the school catering system. Only then could they appreciate its quality. One interviewee explains that more communication with parents is needed because “they are not aware of many things and have a distorted idea of the service, based on children’s feedback.” Another interviewee agrees:

“From a technical point of view, [the supply of meals at home] would be feasible, as is already done for meals for the elderly assisted at home, but I believe there is a cultural legacy in Italy in terms of collective catering at schools, in hospitals or in company cafeterias. In fact, while guaranteeing top quality materials and the supply of nutritionally correct meals, I believe that in Italy the meals prepared by families are seen as a social value and that the conviction is rooted that meals prepared at home are better than those guaranteed by a cafeteria, even if this is often not the case. We are working extensively on food education for students, CMs, and also for parents, to help people understand the quality of the service and the meals provided, but we still have to do a lot.”

According to one interviewee, family lunches have a fundamental value in Italian society and therefore school meals would not have been accepted if delivered at home. A catering company had set up a plan to provide home delivered meals for workers working from home during the pandemic. The interviewee says “it never left, because workers prefer to have food vouchers to buy food and then cook whatever they want. Similarly, it is likely that vouchers would have been more welcomed by families.” The idea that if parents stayed at home during the pandemic they would have no problem preparing meals for their children is well summarized by the words of another interviewee who jokes “parents were at home, they had nothing to do, they were preparing lunch!”. This perception seems to take into consideration only the organizational difficulties that parents had previously had in preparing their children’s meals and not the costs they had to bear.

One respondent concluded that the suspension of the school catering service was taken for granted and nobody imagined that it could be otherwise. This perception contrasts with the awareness that all the interviewees expressed of the importance of school meals in tackling food insecurity. Many interviewees agree that for many children the school meal is the only complete meal of the day and that it would have been a duty to provide alternatives to low-income families. Many interviewees agree that in Italy there is

a need for a step forward at a cultural level, a need to consider the school catering as an essential service, like the school itself, and to make it accessible and free for all. This is commonly referred to as “universal free meal.” To make this change possible, a political decision is needed which can only take place on the basis of a push from society. A change of cultural paradigm is, however, needed, and this currently seems distant in Italian society. The costs of the universal free meal could not be borne by municipalities, which often already have difficulties in supporting the current services with limited budgets, but at the state level.

Discussion

The article analyzes the implementation of measures to prevent the spread of the pandemic within the Italian school catering system. The results of the analysis highlight that the Italian school catering system reacted extremely slowly to the COVID-19 crisis. No alternatives to school meals were organized during the closure of the schools in the first lockdown of 2020 nor in the closure periods that occurred throughout Italy or in individual regions between autumn 2020 and spring 2021, nor during localized closures (for school classes) due to the quarantines that took place in the 2020/21 and 2021/22 school years. As admitted by the respondents, this slowness in reacting to the crisis is a symptom of the failure to recognize the school catering service as an essential service, on par with the school itself. The process which, since the post-war period, through norms and legitimization of technical solutions, had led to considering the school meal as an “institution” (Herpin, 1988; Laporte and Poulain, 2014) carrying social values, was interrupted by the pandemic. More precisely, the traditional social values of the school catering service have waned, sidelined by a new, higher social value, that of health prevention. In examining the interactions between social values, norms, and legitimization of technical solutions, Poulain and Laporte (2021) well-describe how technical solutions are able to convey a specific social value (“a proper meal”) with the consequence of achieving different outcomes in terms of combating obesity in French and British workplace catering set-ups and systems.

As highlighted by the literature cited in the introduction, in many other high-income countries, various alternative measures to school meals were implemented for school-age children, i.e., takeaway lunches, home delivered meals, cash transfers, or food vouchers. During the COVID-19 pandemic, universal school meals were provided in the US in response to the alarming rise in the prevalence of poverty and food insecurity among households with children (Cohen et al., 2022; Zuercher et al., 2022). Kinsey et al. (2020) highlighted the merit of states and school districts responding quickly to the crisis, developing innovative solutions for addressing rapidly changing demands. McLoughlin et al. (2020) stressed the importance of collaboration at community level, i.e., school districts working with the Red Cross, volunteers, and school food staff to address the emergency. Several alternatives were provided in European countries showing adaptation, innovation, and cooperation at community level in the response to the COVID-19 crisis [Global Child Nutrition Foundation (GCNF), 2020; World Food Programme (WFP), 2020a,b,c; Beitane et al., 2021; Ala-Karvia et al., 2022; Beitane and Iriste, 2022]. In Italy, on the contrary, the

school catering system only moved with the reopening of schools, defining the measures that had to be taken to counter the spread of the virus. The practices developed along the catering chain were analyzed with reference to the works of Callon who emphasizes the translation (1984) and performative (2008) dynamics that characterize each action program (Latour, 1992) at the moment of its implementation. According to this analytical perspective, action programs are literally “translated” into practice through a collective process of negotiation among the actors involved and transferred in a precise spatial and temporal context. A pragmatic analysis of the whole procedure—from intention to implementation—has the potential to detect the ways in which the project is translated and performed (Callon and Latour, 1981). Following this approach, the dense description of the technical and organizational processes of school catering, through the punctual narration of the elements that performed the preventive project during the pandemic, demonstrates the predominantly performative nature of the actions implemented. Technical and organizational solutions have been developed and adapted to the local context for responding to government indications as effectively as possible. It also demonstrates that the objectives were negotiated and aligned by catering companies, municipalities, and school managers, leaving out the other social actors of the system (children, teachers, and parents). The translation in practice of the safety and prevention measures focuses on the issue of performativity and on the co-agency role of the materiality (Barad, 2003), neglecting the social component of socio-material practices and progressively compromising the initial social values of the service, in particular those of food security, education, and environmental sustainability.

The action program was implemented both in regulatory and procedural terms, in compliance with safety precautions, and in technical and organizational terms. The security procedures went beyond the ministerial technical-scientific protocols, constituting a non-explicit reassurance for all decision makers, which Lupton (1999) defines as “sociocultural stabilization” through specific judgment criteria, control and verification technologies, meanings, formulae, and symbols. The action program, on the other hand, proved to be weakly connected with the program’s end users, i.e., children, teachers, and, ultimately, parents, revealing a misalignment between health objectives and social, educational, and environmental objectives. The changes that occurred with the pandemic focused on distancing children during meals, with the possibility of eating in the classroom or in the cafeteria, but over several shifts; the use of lunch boxes and disposable tableware to speed up the distribution and consumption of meals, since shifts were contracted; a certain simplification of the menus; and the suspension of food education and service quality control activities by the CMs to avoid unnecessary interpersonal contact. These changes had consequences on the organoleptic quality of meals and reduced consumption and consequently nutritional intake. Barocco et al. (2021) carried out a study to verify the impact of the pandemic on the food security of state school cafeterias in the Province of Trieste and determine any nutritional critical points and corrective actions to guarantee healthy meals for all students. They concluded that the pandemic affected the quality of meals served, in particular that of afternoon snacks and fresh desserts. They suggest the importance of taking action to continuously support

school caterers with technical assistance to overcome the impact of COVID-19.

The educational value of meals was no longer supported by food education activities. Waste of food and material from disposable tableware and single-portion packaging also increased. Attention to the environmental impact of school meals thus ceased.

The suspension of school meals took place in a context of food poverty already entrenched in Italy (Maino et al., 2016) and exacerbated by the pandemic (Saraceno et al., 2022). In Italy, the action to combat food poverty is carried out by a plurality of public and private stakeholders and using different intervention models, but the lack of a strategic framework and institutional coordination, the marginality of the phenomenon of food poverty in social policy, and the fragmentation of law enforcement action make the long-term response to food insecurity ineffective (Galli et al., 2016, 2018; Arcuri, 2019; ActionAid, 2020). The measures adopted during the pandemic to counter the difficulties of low-income families were the distribution of food packages and the provision of shopping vouchers for the purchase of food and basic necessities. These measures have been judged insufficient and inadequate and at the same time the pandemic highlighted the need for a capillary and accessible system to combat food poverty (ActionAid, 2020). In this sense, the role of school catering service is considered crucial in tackling children's food poverty, since for some children, school meal represents the most complete and healthy meal of the day (Save the Children, 2018; Special Rapporteur on the Right to Food, 2020; Autorità garante per l'infanzia e l'adolescenza, 2022). As explained by municipal officials, data on school meal rates and on the population that uses free or reduced rate school meals are held by individual municipalities, which can autonomously decide the rates of the service means-tested according to family income. There is no information aggregated at the national level which would instead be of interest as an indirect measure of Italian food poverty.

In this article, we wanted to explore the point of view of service managers on alternative responses to the suspension of school catering service in the event of school closures. The possibility of providing home delivered meals was excluded by all respondents, citing excessive organizational and logistical complexity and economic unsustainability. The interviewed school catering service managers often come back to the cost of the service and the alleged economic unsustainability of providing an alternative to school meals during pandemic school closures. Further investment is deemed unfeasible. This limit appears to be a measure of the actual social value attributed to the school catering service. Similarly, Poulain and Laporte (2021), analyzing the French and British workplace catering systems, explain that the average cash value of meal vouchers expresses how important catering at work is to decision-makers and corporate catering managers.

For the interviewees, parental acceptability of school meals delivered at home is considered low due to a widespread perception in Italian society that the family meal is always preferable. This perception appears to be in contrast with the increasingly widespread use of takeaway and delivered meal services (Manuelli, 2023). In any case, from our analysis, it emerges that the point of view of families was not taken into consideration in the application of anti-pandemic measures. The aid system based on food vouchers was instead considered easier to implement, even if it derived

from a political choice of the central government because the municipalities were not considered able to bear the necessary cost. Instead, Parnham et al. (2020) concluded that the voucher scheme did not adequately serve children who could not attend school during the pandemic. Against a background of every possible alternative to the suspension of the service, there was a problem of costs and regulatory framework for the service, which is not considered an essential public service, but a public service on individual demand and therefore paid for in whole or in part by families.

There are two major limitations in this study. First, our research highlights the unique perspective of school catering service representatives. Indeed, we collected the points of view of those who manage the school catering service because they know more deeply than anyone else its limits and possibilities of adaptation. At the same time, they reported individual viewpoints, referred to specific corporate and municipal contexts, within the framework of a hopefully exceptional situation. Therefore, the research findings do not allow to generalize. The second limitation concerns the fact that only one researcher performed the analysis and interpreted the data. This might increase the risk of unintended biased opinions due to the researcher's cultural background or perspectives on phenomena investigated. Even though the research findings must be interpreted with caution, they contribute to a reflection, that certainly needs further research, on the importance of Italian school catering system in combatting food poverty and how it can be improved in the future, especially during school closure.

Conclusion

The pandemic created unexpected challenges for the administration of the Italian school catering service. The service was suspended for as long as schools were closed, with no alternatives for children. The complexity of social values with which the school catering service has been invested by public social and health policy in Italy in recent decades disappeared through the absolute carelessness with which this system was suspended for months, after the closure of schools due to the pandemic. Meanwhile, solutions were found in the rest of the world to continue reaching children and young people with school meals. Approximately 2 million lunches and mid-morning breakfasts are served daily in Italian schools (Società Italiana di Igiene Medicina Preventiva e Sanità Pubblica (SIIP), 2020). Access to these meals was disrupted as a result of long-term school closures related to the COVID-19 pandemic, potentially decreasing both student nutrient intake and household food security.

When schools were open, the service changed by responding to preventive measures defined at central government level and implemented locally through coordination between municipalities, catering companies, and schools. Children, teachers, and families, i.e., the service's end users, were excluded from these discussions. The result was a mismatch between pandemic prevention goals and school catering social values.

The recent analysis carried out by the United Nations [World Food Programme (WFP), 2023] describes the state of school catering worldwide in 2022, 2 years after the onset of the

COVID-19 pandemic. School catering is once again one of the largest and most widespread social safety nets in the world and the number of children being reached by school catering programs now exceeds pre-pandemic levels. This rapid and unprecedented rebound has been driven by national political leadership at the highest levels, channeled through the School Meals Coalition co-created in less than a year by political leaders from 76 countries representing 58% of the world's population across all income levels. Italy is not among the member states who joined the coalition (School Meals Coalition, n.d.). The reflection on what happened in Italy during the pandemic developed in this article helps to highlight that there is little interest in the food security of children, confirmed by the absence of a debate on the school catering as an essential service and on the universal school meal in Italian society (Ferrando et al., 2018; Ferrando, 2019). The analysis of what happened during the pandemic can be useful for informing future school food policy for out-of-school time, such as over the summer. Children in low-income families must be protected from the unintended nutritional consequences of school closures. School catering should be considered as a measure of social protection for low-income families, but its role is weakened by the lack of a connection between social services and school catering (Galli et al., 2016, 2018; Save the Children, 2018; Arcuri, 2019; ActionAid, 2020; Special Rapporteur on the Right to Food, 2020). From the pandemic we can learn that the Italian school catering system is ready to respond effectively to emergencies from an organizational and technical point of view, through coordination and teamwork among the main catering players (i.e., catering companies, municipalities, and school managers) aimed at identifying procedural innovations and adapting them to different local contexts. On the other hand, it is not prepared to take on the disruptive phenomenon of food poverty, even failing to imagine the possibility of offering meals to children outside the time and space of school.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was obtained to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

EP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Linking farmers' perceptions and management decision toward sustainable agroecological transition: evidence from rural Tunisia

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Global food systems face sustainability challenges like undernourishment, inequity, resource degradation, and pollution. Food production and consumption drive environmental change with greenhouse gas emissions, biodiversity loss, and land-system shifts. The climate change crisis has intensified concerns about the ecological impact of these systems. Sustainable food networks, such as community-supported agriculture, are promoting sustainable production and consumption through short supply chains. International bodies like the Food and Agriculture Organization (FAO) and the Consultative Group for International Agricultural Research (CGIAR) are also spearheading initiatives for more equitable and sustainable food systems. In Tunisia, where dryland areas predominate, the ongoing implementation of the Agroecology Initiative provides the context for this study, which explores the drivers and barriers of agroecological transformation in this challenging environment. The research focuses on stakeholder engagement, with a gender perspective to explore farmer perceptions. The study, conducted in the northwest of Tunisia in 2022–2023, involved focus groups, workshops, surveys, and questionnaires with various stakeholders. Findings highlight farmer organizations' potential in promoting sustainable farming, with clear goals, diversified systems, and collaborations. However, challenges such as input scarcity, water shortage, low income, and marketing must be addressed. Results also indicate that over 90% of farmers who received assistance with agroecological practices reported a change in their ideas and practices. Fifty seven percent of the workshops participants identified the olive oil value chain as having the greatest potential for agroecological transformation, but it faces constraints such as climate, lack of policy incentives, training, funding, and difficulty in adopting technical innovations. Women's inclusion in agriculture, environmental, social, and economic challenges were also highlighted. Despite these obstacles, key drivers for agroecological transition were identified. These include the compatibility of many agroecological practices with existing farmer capabilities, their cultural and economic benefits, and the positive outcomes for environmental sustainability and health. The study advocates for a socio-technical systems analysis to address the root causes hindering Tunisia's agroecological transformation. A participatory approach is crucial to understanding priorities and developing a sustainable and resilient food system. Furthermore, the research underscores the importance of considering diverse farmer perspectives and tailoring strategies to support this critical transition effectively.

KEYWORDS

participatory approach, agroecological transformation, perceptions, resilience, value chain, North Africa

1 Introduction

Global food systems are struggling to achieve sustainable development goals, contributing to undernourishment, inequity, natural resource degradation, and environmental pollution. Current food systems are vulnerable to multiple shocks, such as climate change, economic crises, and pandemics, which can have cascading effects on smallholder food security. The rising prices of fertilizers and food imports resulting from these shocks have rekindled interest in the call for a policy shift toward agroecology (1). Food production and consumption are major contributors to global environmental change, including greenhouse gas emissions, biodiversity loss, and land-system change (2).

Alternative food networks, such as food cooperatives and community-supported agriculture, aim to promote sustainable production and consumption through short supply chains and connections between consumers and producers. These networks also foster social interactions and collective mindfulness for a sustainable food system. Producers face both pressure and opportunities to incorporate sustainability into their business practices to meet consumers' expectations. The agroecological transition is a promising approach to create more equitable and ecologically sustainable food systems (3). Agroecology is the application of ecological principles to agricultural systems, offering solutions to farming and food security challenges such as drought, hunger, poverty, and inequality (4). It supports small-scale farmers in diversity and ensures a long-term balance between food production and the sustainability of natural and environmental resources. It also transforms food systems and ensures resilience by balancing between socio-economic and environmental facets.

According to Dagunga et al. (5), promoting agroecology in smallholder farming communities faces both challenges and opportunities. Some of the opportunities for promoting agroecology, include the potential for increased productivity, improved soil health, and enhanced biodiversity. However, there are many challenges to this transition, such as institutional, social, technical, economic, and environmental factors. These challenges include limited access to resources, such as land, water, and capital, as well as inadequate policy support and institutional frameworks. Additionally, there may be cultural and social barriers to the adoption of agroecological practices (6). Previous research also highlights the importance of participatory approaches and knowledge sharing in promoting agroecology among smallholder farmers (5).

International bodies like the Food and Agriculture Organization (FAO) and the Consultative Group for International agricultural Research (CGIAR) are introducing initiatives to promote more equitable and ecologically sustainable food systems. The agroecological transformation initiative,¹ which promotes good governance of

natural resources, input reduction and biodiversity, as well as social and cultural inclusion, equity, and knowledge sharing, is seen as an opportunity for a shift toward more sustainable, inclusive, and resilient food systems (7).

This study is part of the "Agroecological Transformation in Food, Land and Water Systems" initiative launched by the CGIAR and implemented in Tunisia by the International Centre for Agricultural Research in the Dry Areas (ICARDA). This research contributes to addressing the climate change crisis and to enhancing the resilience of food systems. This research aims to investigate the barriers of agroecological transformation in the dryland context based on the involvement of the different stakeholders with a special emphasis on farmers' beliefs, experiences, and characteristics. Farmers' perception is analyzed, considering the gender perspective. Focusing on dryland areas is crucial due to their unique challenges and characteristics such as water scarcity, erratic rainfall, and fragile ecosystems. Contrasting with more temperate or humid regions, the dryland context requires tailored solutions that consider the specific needs and constraints of farmers operating in these environments.

2 Conceptual framework

Conventional expert-led change assessment methods based on top-down approaches generate quantifiable indicators that allow regional or national comparisons. However, they have certain shortcomings, such as alienating local communities and failing to capture the views of diverse stakeholders (8). Involving the community in evaluation procedures means that indicators are more relevant and specific to the context and evolve over time with the community. Participation leads to the empowerment and capacity building of communities to address emerging challenges in their local environment (8). The agroecological transition is a process that involves the adoption of innovative practices that aim to balance productivity with environmental protection. These practices require a significant change in the way farmers manage their crops and natural resources. Therefore, the adoption of agroecological innovations is subject to various uncertainties and risks, which can influence farmers' perceptions of the innovation (9). Perceptions, which refer to individuals' interpretations and understanding of received information, play a crucial role in the agroecological transition. In this context, farmers' perceptions of innovation can greatly shape their willingness to adopt it. These perceptions can be influenced by various factors, such as the perceived advantages and drawbacks of the innovation, the compatibility with existing practices, the level of information and experience, and the social and cultural context (10).

To understand the role of perceptions in the agroecological transition, researchers use various experimental methods, such as surveys, interviews, or focus groups. These methods help identify the factors that influence farmers' perceptions of innovation and how these perceptions impact their decision-making process (11, 12).

¹ More about this initiative can be read here: <https://www.cgiar.org/initiative/agroecology/>.

According to Roussy et al. (12), the factors that influence the adoption of agricultural innovations by farmers are observable and unobservable. Three main categories are identified as observable: external factors, internal factors, and innovation-specific factors. External factors include market conditions, policy environment, and social networks. Internal factors include farmer characteristics, farm characteristics, and risk attitudes. Innovation-specific factors include characteristics of the innovation, information sources, and adoption process (Figure 1).

Considering farmers' perceptions of these factors in the agroecological transition can help researchers and policymakers design and promote innovations that are more likely to be accepted and adopted by farmers (13). By understanding farmers' perceptions and addressing the factors that influence them, it is possible to accelerate the transition toward more sustainable and environmentally friendly agricultural practices. Understanding farmers' perceptions and strategies highlights the need to involve multiple actors in co-constructing policies and plans to address challenges in food systems. Additionally, farmers' perception-centered approach emphasizes the significance of integrating and sharing knowledge from different sources to enhance agricultural productivity and improve the delivery of agricultural extension services to small-scale farmers (14). The literature underscores the importance of stakeholder engagement, innovation management, and entrepreneurship development. It emphasizes the need for a systematic and integrative approach to understand the relationship between these concepts and foster sustainable innovation while considering the interests and concerns of various stakeholders in decision-making processes (15–17).

Another classification of the factors influencing the agroecological transition is revealed according to many studies (Figure 2). These factors are categorized into personal, technical, economic, and social factors. Personal factors pertain to the specific characteristics and

beliefs of individual farmers, while technical factors include the knowledge, skills, and resources required for agroecological practices. Economic factors encompass the availability of funds and economic incentives to support the transition. Social factors, on the other hand, are influenced by external factors such as access to grants, markets, and community attitudes (3, 9, 18). These factors are interconnected and can collectively shape the success or barriers to the agroecological transition. Understanding and weighing these factors is crucial when developing strategies to promote sustainable and resilient food systems.

3 Methodology

The research methodology is based on a participatory approach supplemented by quantitative and qualitative analysis. The case study is conducted in the northwest region of Tunisia characterized by a mixed tree-crop-livestock farming system.

3.1 Study site

Located in northwest semi-arid zone of Tunisia, the Kef-Siliana transect (Figure 3) has been designated a priority zone by the Agroecology Initiative (19) due to its vulnerability to both soil erosion and climate change (20). While Siliana and Kef governorates both experience a continental climate, their rainfall and temperature ranges differ slightly. Siliana receives between 350 and 550 mm of rain annually with temperatures ranging from 3.2 to 35.7°C, whereas Kef experiences an average annual rainfall of 350 mm to 450 mm and temperatures varying from 7.3 to 26.5°C. These predominantly rural regions face socioeconomic challenges such as high poverty rates, unemployment, and limited access to basic services, leading to

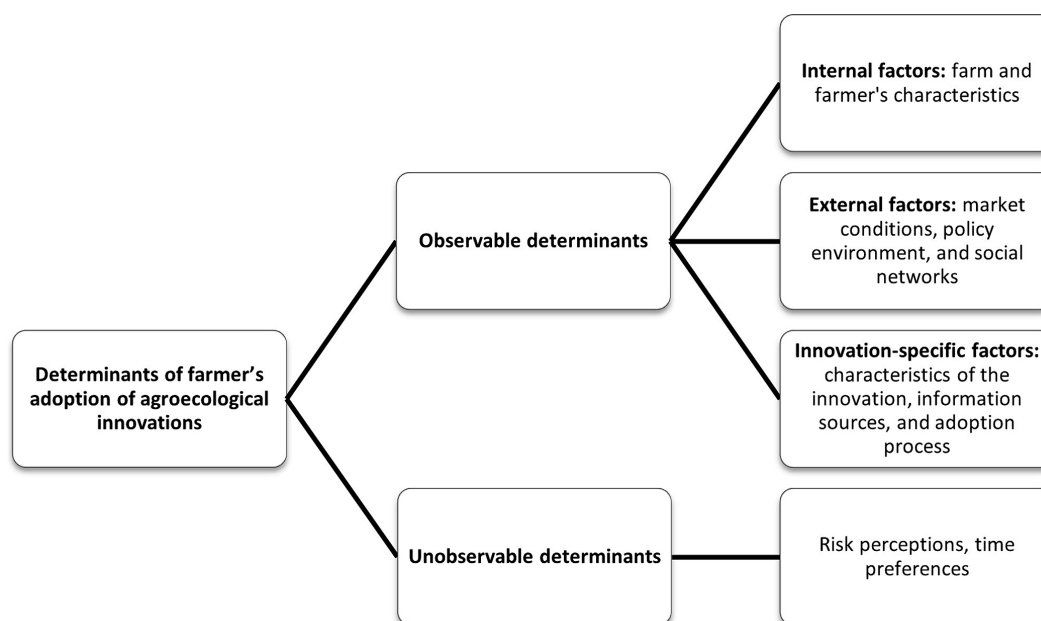


FIGURE 1

Factors influencing farmers' adoption of agroecological innovations, adapted from Roussy et al. (12).

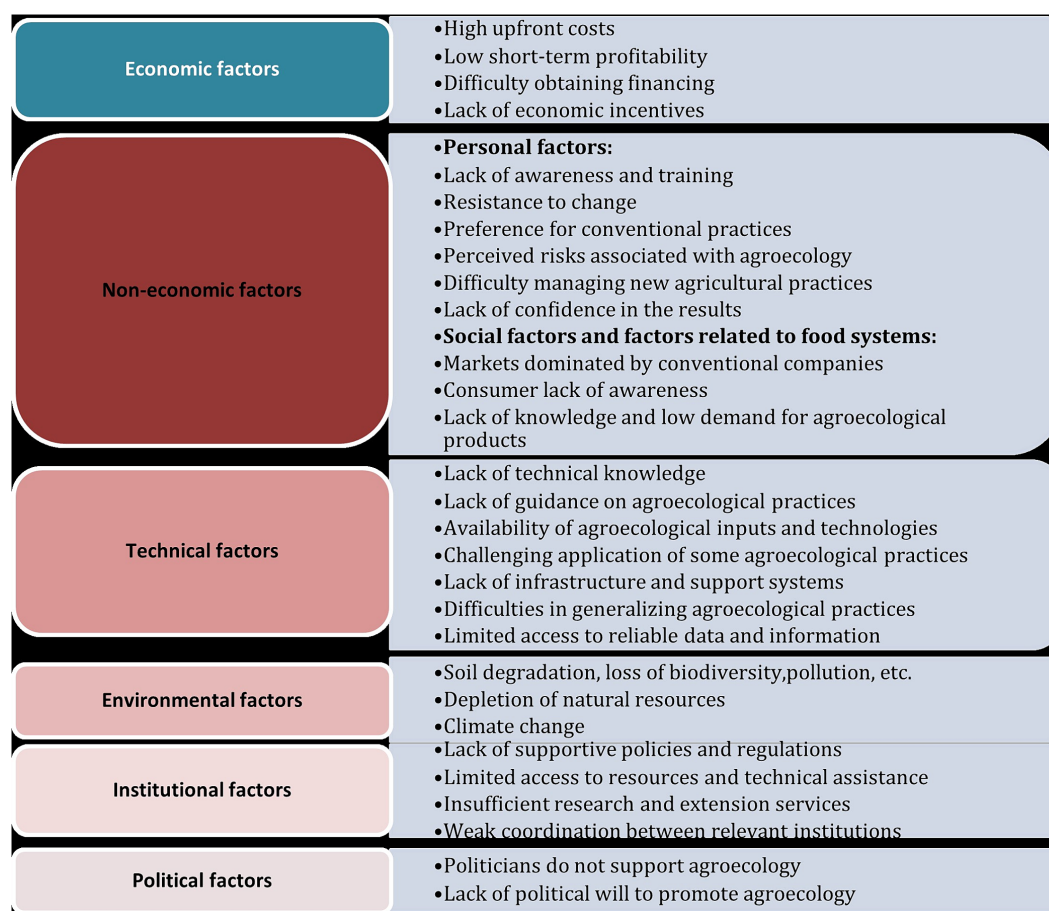


FIGURE 2
Categories of the factors influencing the agroecological transition.

significant outmigration, particularly among young people. Despite these challenges, the transect boasts a diversified agricultural system, including cereal crops, livestock farming, and olive tree cultivation. This agricultural diversity reflects the complex interdependence of various sectors and the complexity of the regions' resource utilization patterns (21, 22).

3.2 Data collection

The research involved semi-structured interviews, focus group discussions, workshops, a survey, and a closed-ended questionnaire. The participants were identified based on their expertise, involvement in the initiative, and their roles in the agroecological transition landscape. The selection process has involved reaching out to academic and research institutions, governmental bodies, extension services and other relevant stakeholders to ensure a diverse representation of expertise and perspectives in the study. Table 1 summarizes the different sources of the collected data, the details of the respondents, the research questions, and the methods of analysis. The data were collected in (7) through semi-structured interviews with four professional farming organizations, workshops with farmers, technicians, researchers, public and private stakeholders from various value chains, and an open-ended survey carried out among 69 farmers

belonging to farmers' organizations. Additionally, a questionnaire about the perception of the agroecology transformation barriers and drivers was conducted with 35 farmers engaged in the initiative.

3.3 Data sources

The semi-structured interviews and the focus group discussions were conducted with four farmers organizations included in the Tunisian agroecological living landscape in the transect Kef-Siliana. The agroecology initiative is built around the concept and approach of living landscape to integrate the socioeconomic-system and ecosystems in one site to implement and test the agroecological transition (19). The Tunisian living landscape is characterized by the urgent need to enhance natural resource management, foster agricultural innovation, and address climate change impacts effectively. The main objectives of the interviews were to describe the key characteristics of each farmers' organization and their main activities. To explore the diversity of the key partners and to discuss the main issues/challenges and their propositions to see how the agroecology approach could satisfy their needs.

The workshops were instrumental in identifying the opportunities and challenges to the agroecological transformation and selecting the main value chains with the greatest potential for

boosting this transformation. The selection was based on a global evaluation matrix prioritizing the value chains according to a set of predefined criteria based on agroecological principles and their economic, social, and environmental dimensions or criteria (20). These selection criteria are summarized in Table 2. The research by

Di Vita et al. (24) and Spina et al. (25) underscores the importance of employing value chain methodologies. Through a holistic approach that involves establishing a focus group with thematic nodes and topics, involving national-level actors and experts, collecting data via interviews, and rigorously processing the gathered information, a comprehensive framework is developed to enhance understanding and decision-making in the field.

The survey explores the influences of farmers' organization on innovative farming practices. It includes questions on the impact of agricultural demonstrations on farmers' understanding and practices, on trade between farmers, on collective investment, on the perception of the organization of farmers in the community, and on the inclusiveness, exchange of information, commitment, and participation of women within the farmer organization, as well as on contracts and services between the farmer organization and farmers.

The questionnaire on perception is designed based on the factors that were identified in the theoretical framework as influencing the agroecological transformation. It is structured into several sections. The first section focuses on the socio-economic characteristics of the farmers, including age, gender, location, education level, land ownership, main farming activities, and years of experience. The second part of the questionnaire explores the farmers' perceptions of the agroecological transformation in Tunisia. This section is further divided into four subsections. The first subsection addresses the effects of agroecological practices, the second subsection focuses on the farmers' capabilities, and the third subsection delves into the difficulties and challenges associated with transformation. The fourth subsection of the questionnaire deals specifically with technical barriers. It is important to note that the active participation in the agroecological transformation was a selection criterion for all the respondents.

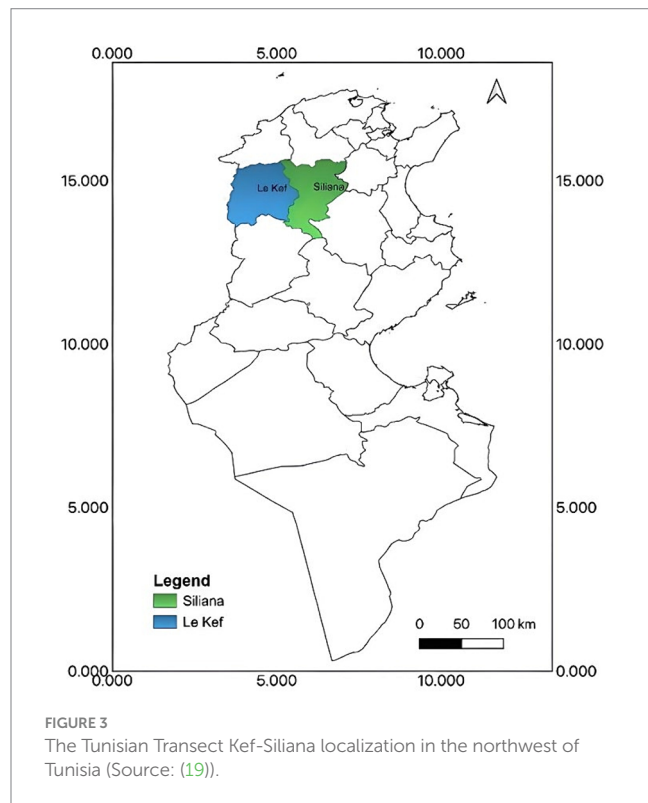


TABLE 1 Overview of data Sources, participants, research questions, and methodology.

Data sources	Respondent details	Research questions	Methods	When used
Four semi-structured interviews and focus group discussion	Four professional organizations of farmers	What is the level of engagement of local communities in developing a specific context for agroecology transformation?	Qualitative analyses, SWOT analysis	May 2022
Two workshops	66 participants: 16 farmers, 14 technicians, 10 researchers, 26 public and private actors from the different identified value chains (notably the olive tree, sheep meat, cereals, honey, and milk)	Which value chains have the most potential to boost the agroecological transition?	An evaluation matrix prioritizing value chains according to agroecological principles	December 2022
A survey	69 Farmers	How do farmers perceive the change toward an agroecological system through project interventions? How does the organizational factor influence the agroecological transformation in the Tunisian context?	Quantitative analyses BBN visualization Descriptive analyses Kendall W test Kruskal-Wallis Test	November 2022
A questionnaire	40 farmers involved in the Agroecology initiative	What are the main boosters and inhibitors of the agroecological transformation considering the current perceptions and characteristics of farmers?	Descriptive analysis Kendall W test Factorial analysis	March 2023

Source: Author's elaboration (7).

TABLE 2 Dimensions for the selection of the value chains.

Economic criteria	Environmental criteria	Social criteria
• Job creation opportunities • Market demand prospect • Income generation • Comparative advantage of the production • Level of competitiveness	• Environmental impact of the value chain • Impact of the environment on the value chain	• Integration of local actors • Improving working conditions

Source: Adapted from Jochem (20).

TABLE 3 Characteristics of the farmers.

	The survey	The questionnaire on perception
Total number of farmers	69	35
Number of female farmers	38	6
Number of male farmers	31	29
Age range (years)	22–73	21–72
Average age (years)	48	51
Location	Transect Kef-Seliana and Kairouan	Transect Kef-Seliana
Main crops	Livestock, cereal crops, olive trees	Olive trees, cereal crops, livestock
Land holdings range (ha)	1–50	0–100
Average land holdings (ha)	9	17

Source: Author's elaboration from analysis of field data (2023).

3.4 Respondents' characteristics

An overview of the characteristics of the farmers included in the survey and in the questionnaire is included in Table 3. The survey was conducted on a total of 69 farmers, with 38 female and 31 male farmers, while the questionnaire on perception was conducted on 35 farmers, with 6 female and 29 male farmers. The farmers are in Transect Kef-Seliana and Kairouan, with a primary focus on livestock, cereal crops, and olive trees as their main crops.

The land holdings of the farmers range from 1 to 50 hectares in the survey and 0–100 hectares in the questionnaire, with an average of 9 and 17 hectares, respectively. The age range of the farmers is between 22 and 73 years, with an average age of 48 years for the survey and 51 years for the questionnaire.

3.5 Analytical methods

Descriptive statistical analysis was conducted using various basic statistical measures, including mean, standard deviation, maximum, minimum, frequencies, and percentages. In addition, several analytical techniques were employed, such as SWOT analysis, Chi², correlation, Kendall W and Kruskal-Wallis tests, Bayesian Belief Network (BBN) visualization, and factorial analysis. These methods were performed to accomplish several objectives: determining the level of engagement of local communities, prioritizing value chains with high agroecological potential, evaluating the progress toward an agroecological system through project interventions and farmers' organizations, and assessing and categorizing the different drivers and barriers in the agroecological transformation of the Tunisian food system. The software tools SPSS and Stata were utilized for these analyses.

3.5.1 The SWOT analysis

The SWOT analysis is a strategic tool that helps identify the strengths, weaknesses, opportunities, and threats associated with projects and businesses (26, 27). Its primary purpose is to evaluate both external and internal factors that either support or hinder the progress and successful implementation of projects or programs, aiding in making informed operational decisions (28). This analysis provides a framework for the strategic development of programs or projects, and it has been widely used to explore the internal and external environments, enabling the formulation of strategies and decision-making approaches for projects and programs (29). However, in the context of agroecology research, the SWOT analysis does encounter certain limitations. These limitations encompass subjectivity, the absence of quantifiable metrics hindering precise numerical assessments and comparisons, the dynamic nature of factors necessitating ongoing updates, and the limited focus on interactions, which may not fully consider how different factors in agroecosystems interact and influence each other. This can overlook important connections and complexities within agricultural systems, which are crucial for sustainability and resilience (30, 31). It is crucial to consider these limitations to ensure a comprehensive and balanced evaluation of agroecosystems. Despite the SWOT analysis limitations, it remains relevant in the literature due to its usefulness in exploring possibilities during the decision-making process and its flexibility in combination with other approaches (32–34).

3.5.2 Bayesian belief network

A Bayesian Belief Network (BBN) is a graphical model that represents the probabilistic relationships between different variables. It is a powerful tool for understanding the complex interdependencies among variables and their influence on each other. BBNs are particularly useful for analyzing and visualizing data in fields such as

decision analysis, risk assessment, and machine learning (35). In the context of this study, the BBN was used to visualize the relationships between different variables related to perceived changes. It helped to identify and understand how changes in one variable were connected to changes in other variables, providing insights into the overall impact of project interventions.

3.5.3 Factorial analysis

A principal component analysis with a varimax (orthogonal) rotation method is applied to perform exploratory factor analysis. The aim of this analysis was to obtain a factor structure of Agroecological transition perceived drivers and barriers, with both empirical and conceptual support (36). To determine the applicability of factor analysis, Bartlett's test of sphericity ($p < 0.05$) was used. The number of factors to retain was decided by applying the criteria of eigenvalues greater than 1 (37). Finally, the extracted factors were labeled to give each factor a meaningful definition and meaning for interpretation.

4 Results and discussion

4.1 Level of engagement of local communities

The general characterization of the four farmers' organizations is summarized in Table 4. The farmer organizations have diverse social and technical histories, allowing for the study of agroecological transition dynamics under various social and policy configurations. Farmer Organization 1, established in 2015, focuses on livestock and diverse agricultural production on smaller land holdings, with an exclusively female membership. In contrast, Farmer Organization 4, founded in 2017, specializes in cereal cultivation and livestock farming on larger land areas, boasting a more gender-balanced composition (50% women). Farmer Organization 3, established in 2020, centers its activities around olive trees, fruit trees, and beekeeping on moderate-sized land holdings. Farmer Organization 2, founded in 2022, is primarily involved in livestock farming and cereal crop cultivation on medium-sized land areas, with the lowest number of members and only 11% female representation. These organizations often develop

common projects and actions, and their area and number of beneficiaries reflect their radius of action and capacity for scaling out.

The SWOT Analysis is performed to assess the agroecological transition potential of the farmer organizations in the transect Kef-Seliana. The findings show that the farmer organizations promote diversified and sustainable farming systems that align with agroecological principles and facilitate a variety of agroecological practices. The key points identified from the SWOT analysis are included in Table 5.

The interviewed farmer organizations have successful projects and collaborations with various key partners, such as The German International Cooperation (GIZ), The International Center for Agricultural Research in the Dry Areas (ICARDA), and the Regional Agricultural Development Commissariat (CRDA), to access resources, expertise, and funding opportunities. They have implemented various activities, such as local food artisanal production, conservation agriculture practices, crop rotation, forage mixtures (cereal-legumes), mechanization, forage seeds distribution, access to finance, and capacity building, which contribute to environmental and farming sustainability and connectivity. The diversified membership, with a focus on women and young farmers, aligns with the agroecological principle of social equity and justice. While Farmer Organization 1 had 100% female adherents and Farmer Organization 3 had 70% women adherents, Farmer Organization 2 only had 11% women members. Similarly, the percentage of members less than 35 years old varied across the organizations, with Farmer Organization 1 having 20%, Farmer Organization 2 having 11%, Farmer Organization 3 and 4 having 40%. This diversity in gender and age representation highlights that not all farmer organizations in Tunisia exhibit the same level of inclusion of women and young farmers. However, all the studied organizations encourage economic diversity and have a clear purpose in contributing to good governance. According to many studies, farmers' collectives have different approaches for supporting agroecological transitions, including funding, advice, capacity building, experimentation with new practices, and information exchange (38, 39). Diversified Farming Systems include functional biodiversity in farming practices to maintain ecosystem services like soil fertility, pest and disease control, water use efficiency, and pollination (40). Besides, crop rotation and legumes were identified as

TABLE 4 General characterization of the farmers' organizations.

	Farmer organization 1	Farmer organization 2	Farmer organization 3	Farmer organization 4
Establishment date	2015	2022	2020	2017
Number of members	6	3	3	9
Number of adherents	55	27	114	120
Number of beneficiaries	55	101	240	500
% of women adherents	100%	11%	70%	50%
% less than 35 years old	20%	11%	40%	40%
Main activities	Livestock, Bee keeping, poultry, saffron and vegetable production.	Livestock, cereal crops, olive trees	Fig trees, Olive trees, Cherry trees Beekeeping Cereals	Livestock, cereal crops, olive trees
Land holdings range	2–3 ha	5–20 ha	0.5–5 ha	20–200 ha

Source: Author's elaboration from analysis of field data (2023).

TABLE 5 SWOT analysis assessing the agroecological transition potential of the farmer organizations.

Strengths	Weaknesses
- The farmer organizations have clear goals and objectives, such as rural women empowering, promoting sustainable rural development, and facilitating access to inputs for adherents. - Farm activity diversification, including cereal crops, beekeeping, livestock breeding, and olive trees, which allows for a variety of agroecological practices. - The farmer organizations offer a range of services such as local food artisanal production, commercialization, mechanization, forage seeds distribution, access to inputs, and capacity building.	- Challenges and constraints in farm activities, such as the unavailability of seeds and fertilizers, water shortage, small income availability, unavailable and expensive pellets, diseases, marketing issues. - The limited membership and adherence to the farmer organizations and limited financial resources and income. - Farmer organizations have limited decision-making power.
Opportunity	Threats
- Farmer organizations can promote new agroecological practices, such as seed multiplication, direct seeding against erosion, animal feed own production, and by-products recycling. - Farmer organizations benefit from partnerships with organizations by receiving technical assistance, equipment, and training. - More diversified economic activities and income sources. - The increasing number of adherents, especially among young people and women.	- Climate change, drought, and soil erosion. - Conflicts among extended families and limited decision-making power. - Limited market access outside the region, especially for perishable products. - Limited access to microfinancing, which hinders farmers' capacity to invest in new agroecological practices.

Source: Author's elaboration from analysis of field data (2023).

the most adequate diversification strategies for intensive rainfed cereal-based cropping systems (41).

4.2 High-potential value chains for agroecological transition

During the workshops conducted with the different stakeholders, many potential value chains were identified including the olive oil, honey, and sheep value chains. Among 33 and 30 participants, respectively in Kef and Siliana, 18 participants in both locations have selected the olive oil value chain as the value chain with the highest potential to integrate agroecology principles, as indicated in Figure 4.

The prioritization of value chains for the agroecological transition in Tunisia highlights the olive oil sector as the most promising for development, considering economic, social, and environmental factors. Table 6 presents the participants motivations regarding the selection of the olive oil value chain.

4.3 Agroecological assessment of the olive oil value chain

The stakeholders present in the workshops were asked if the olive oil value chain can integrate the agroecological principles. The 13 principles of agroecology (42) applied to the selected value chain are presented in Table 7.

Several research studies have backed the views of different stakeholders and considered the multi-stakeholder perspective to identify the obstacles and prospects in the food products' value chains (24). The goal is to identify potential innovations that align with the needs and perceptions of the stakeholders (16, 43, 44). According to Torquati et al. (45), short extra virgin olive oil supply chains enhance agricultural products' sustainability, with no real trade-offs when considering value chain results and environmental impact. In the context of the Tunisian olive oil supply chain, an optimal configuration incorporating organic farming, biodynamic growing techniques, and

a two-phase extraction system using wet pomace for compost preparation is recommended (46). Circular economy principles can be implemented in the olive oil supply chain, but overcoming technological barriers and knowledge gaps is crucial for advancing circularity in the Mediterranean region's agroecological systems (47).

4.4 Farmers' perceptions of change

The aim of the survey was to understand how farmers perceive the change toward an agroecological farming system based on project interventions, and what is the influence of the organizational factor in this transformation in the Tunisian context. The descriptive analysis reveals that over 91.3% of farmers who received training and assistance with agroecological practices as part of ICARDA projects reported a change in their ideas and practices, while around 8.7% reported no change at all. These results confirm the findings of Oppong et al. (48), indicating that farmers in Ghana's semi-deciduous region face challenges in adopting climate-smart agricultural practices due to lack of training, government support and extension officers. According to Šumane et al. (49) redesigning the farming systems, necessitates farmer engagement in practices and local knowledge production. Integrating researcher and support-oriented strategies to bridge theory and practice is crucial for sustainable agroecological farming systems development (50).

Table 8 illustrates the number and percentage of farmers adopting and not adopting new agroecological practices by age and gender. The project suggests incorporating agroecological practices such as intercropping, direct seeding, minimal tillage, and crop rotation. The total percentage of female respondents is higher than male respondents, with 55 and 45%, respectively. The highest percentage of adopting farmers is in the 41–60 age group, with 36.5% of female respondents and 20.6% of male respondents.

The Pearson chi-squared (χ^2) test showed no significant association between location and the adoption of new practices (with a Pearson χ^2 statistic of 0.3570 and a p -value of 0.550) or between gender and the adoption of new practices (Pearson $\chi^2 = 0.3570$,

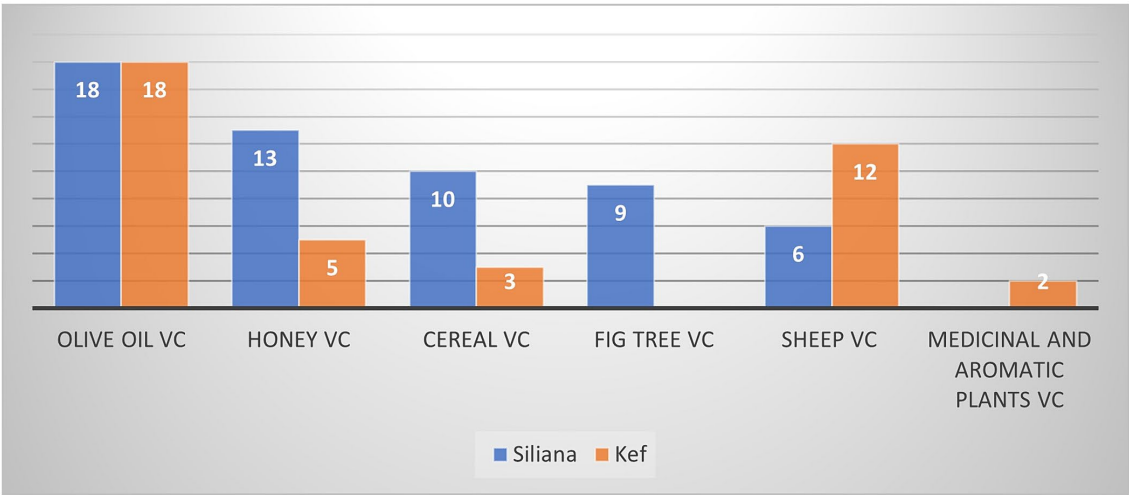


FIGURE 4
Stakeholder preference for value chains integrated with agroecology principles in Kef and Siliana.

TABLE 6 Olive oil value chain selection dimensions and arguments.

Value chain selection dimensions	Participant motivations
Economical	<i>High value creation:</i> Olive oil production offers significant potential for generating added value, especially through the production of high-quality olive oil. <i>Expanding industry:</i> Olive cultivation is experiencing a steady growth in the transect, replacing less profitable crops. <i>Rising demand and price:</i> The market for olive oil is expanding due to increasing local and international demand, coupled with an attractive price for producers.
Social	<i>Cultural significance:</i> Olive oil is a cherished product, holding deep symbolic value for both consumers and farmers. <i>Community building:</i> Olive cultivation strengthens social bonds, particularly during the harvest season (a festive period) and by providing employment opportunities throughout the value chain. <i>Skilled workforce:</i> The region boasts a highly skilled workforce of olive farmers who possess extensive knowledge of olive tree cultivation.
Environmental	<i>Climate-resilient crop:</i> Olive trees are well-adapted to the changing climate, requiring minimal inputs, energy, and water. Additionally, the olive trees contribute to a balanced ecosystem. <i>Waste reduction:</i> Olive cultivation is an eco-friendly practice that utilizes byproducts like olive marc, leaves, and olive tree trunks.

Source: Author’s elaboration from analysis of field data (2023).

Pr=0.550). These results could be explained by the high level of adopting farmers among the respondents. The correlation coefficient between the adoption of new practices and farmer’s age is -0.051 , indicating a very weak negative correlation. However, the p -value (0.677) suggests that this correlation is not statistically significant. However, many studies reveal that age of farmers have a negative effect on the adoption of sustainable agriculture practices (51–54).
Farmers’ perceptions of the change after research and development projects reveal varying levels of endorsement. In terms of motivation and engagement, change in farming comprehension and practices, and improved information exchange between farmers, these aspects are perceived very positively (Mean = 0.95, 0.92, and 0.91, respectively), indicating strong support for agroecological initiatives (Supplementary Appendix 1). Factors related to inclusiveness of small farmers (Mean = 0.87), participation of women (Mean = 0.78), and commercial exchange between farmers (Mean = 0.70) are viewed more moderately. On the other hand, perception of investment in collective activities

(Mean = 0.56) and better services and contracts between the farmers’ organization and agricultural producers (Mean = 0.49) are comparatively lower, suggesting a more nuanced view or potential challenges. Understanding these nuanced perspectives is crucial in tailoring interventions and promoting sustainable agricultural practices.
Through the chi-squared test, statistically significant linkages between various aspects of the perceived change are identified (Supplementary Appendix 2). The visualization via the Bayesian Belief Network (BBN) allows for understanding the complex interdependencies between the different variables (Figure 5). The farmer’s perception of changes in motivation and engagement is linked to the perception of changes in women’s participation and to the enhancement of services and contracts with farmers’ organizations. Likewise, the perception of a better understanding of farming practices is connected to the change of farming practices and to a better information exchange between farmers.

TABLE 7 The agroecological principles applied to the olive oil value chain.

Principles	Olive oil value chain
1. Recycling	Wood shredding, using wood as livestock feed, composting, producing charcoal, using olive pomace as livestock feed, utilizing olive water as fertilizers, and using wood in the manufacture of small tools.
2. Input reduction	The olive tree is a low-input crop that can benefit from the use of compost, legume crops as manure, good soil management, and reduced pesticide use.
3. Soil health	Olive plantations help floor fixing and erosion control.
4. Animal health	Olive tree can serve as an animal shelter, it is used as a livestock feed and a source of bee feeding.
5. Biodiversity	Genetic potential in the olive crops. Olive trees can be planted with other trees and can be used as windbreaks to protect other corps.
6. Synergy	There is an ecological interaction between production units, improves water retention capacity, provides food for livestock, water, and soil conservation.
7. Economic diversification	Olive tree provides an income diversification through procuring income in winter, olive is a non-perishable product, and can be sold at any time, by-products can provide additional income, valorization of sub-products improves the farmers' income, if farmers follow the technical package the productivity will improve.
8. Co-creation of knowledge	Transfer of knowledge, exchange of olive varieties between farmers, co-creation of knowledge can be realized in case the farmers are in an association.
9. Social values and diets	Local product, creation of a label, and high nutritional value.
10. Fairness	Olive oil value chain guarantees decent livelihoods in case there are large areas planted or in case there is intercropping.
11. Connectivity	Sales circuits are short, purchase at the farm, at the oil mill, total lack of connectivity between the institutions in the value chain structures, lack of trust between producer and consumer, an electronic platform on the internet needs to be established.
12. Land and natural resource governance	Institutional support, sector regulation, presence of specialized organizations, and land division due to inheritance.
13. Participation	Limited participation of support organizations (ONH, CRDA, IO, ODESYPANO)*, limited involvement in olive variety choices and in decision-making in general.

Source: Author's elaboration from analysis of field data (2023).

*ONH, National Oil Office; CRDA, Regional Agricultural Development Agency; IO, Olive Institute; ODESYPANO Office for the Development of Silvo-Pastoral Systems in the North-West.

TABLE 8 Farmer's adoption of agroecological practices by age and gender.

Age of respondents	Non adopting farmers		Adopting farmers		Total respondents	
	Men	Women	Men	Women	Men	Women
20–40	1 (16.6%)	0	11 (17.4%)	6 (9.5%)	12 (17.3%)	6 (8.7%)
41–60	0	4 (66.6%)	13 (20.6%)	23 (36.5%)	13 (18.8%)	27 (39.1%)
61–75	1 (16.6%)	0	5 (8%)	5 (8%)	6 (8.7%)	5 (6.2%)
Total	2 (33.3%)	4 (66.6%)	29 (46%)	34 (54%)	31 (45%)	38 (55%)

Source: Author's elaboration from analysis of field data (2023).

Information exchange between farmers is related to the perception of a better commercial exchange that also associated to the enhancement of services and contracts with farm organizations. Only the perception of inclusiveness and collective investments are not connected to other aspects of change. The identification of these interlinks helps prioritizing the intervention areas where interventions had the most significant impact. A higher perceived motivation and engagement suggests the effectiveness of interventions in that domain and may impact women participation and the enhancement of services and contracts with farmers' organizations. The project's interventions were also effective leading to a high perceived understanding of farming practices that improves the information exchange between farmers and farming practices change. This insight can guide the design of future interventions based on the identified associations, leading to more targeted and impactful interventions.

The findings suggest a significant association between gender and the perceptions of motivation and engagement in agricultural projects ([Supplementary Appendix 3](#)). A strong association is identified between gender and the women's participation perception and the perception of better services and contracts between farmers and farmer organizations. The study shows that the perception of change on motivation and engagement increases from 95 to 100% if all respondents are women, while the women's participation perception increases from 78 to 98% ([Figure 6](#)). These results are consistent with several studies that have explored the role of gender in agricultural projects. Cloete et al. (55) found that rural Nicaraguan women's motivations change from initial to sustained forms, enabling them to sustain community-led projects and build social capital, self-efficacy, and agency. Amran and Fatah (56) studied women's empowerment in agriculture in Malaysia and found that access to extension services and effective

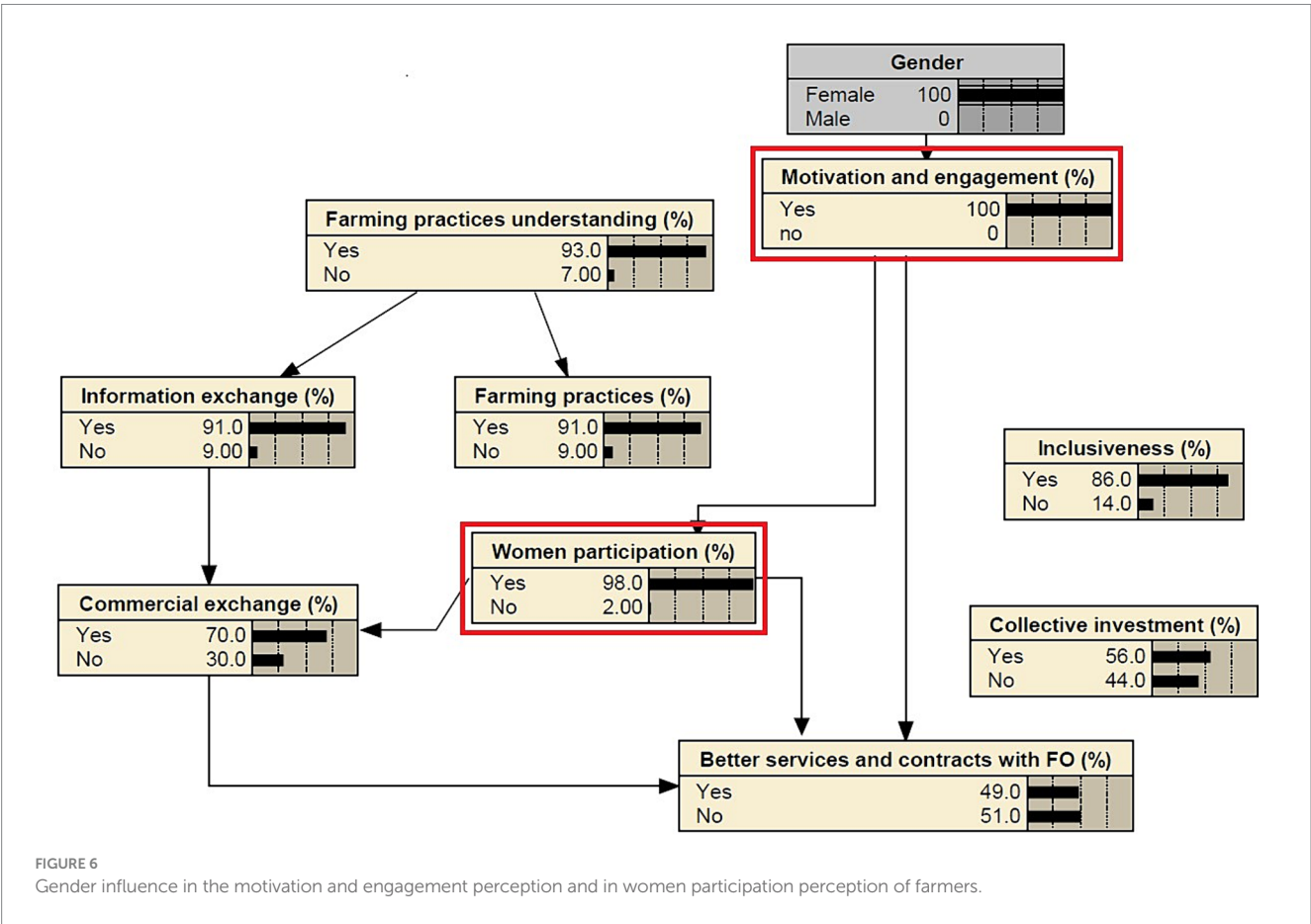
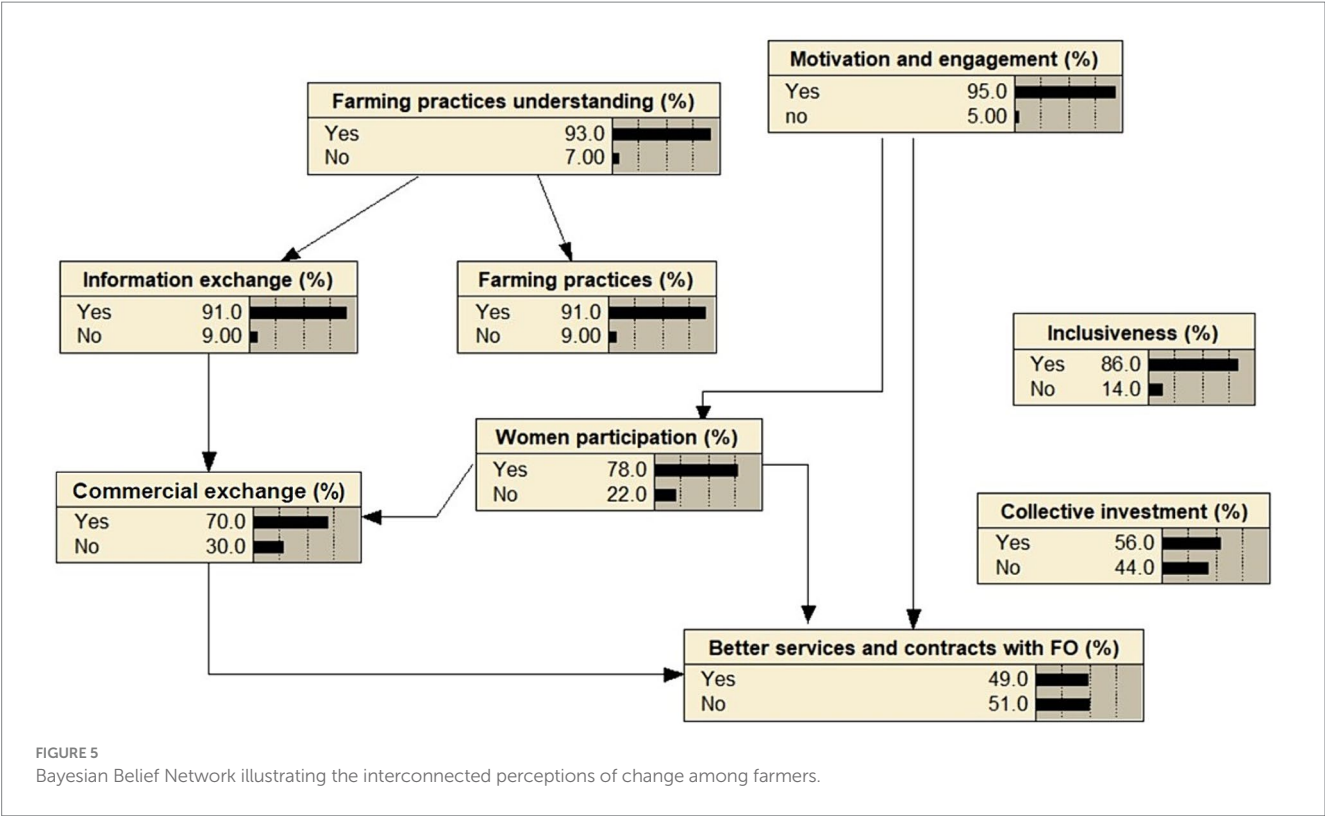


TABLE 9 Responses on farmer's perceptions of farmers' organization effects on changing practices and decisions on the farm ($n = 69$).

Items	SD	D	N	A	SA	Mean	Standard deviation	Decision*
Effect on changing input purchasing behavior	13 (19%)	3 (4%)	9 (13%)	16 (23%)	28 (41%)	3.62	1.51	Low perception
Effect on changing practices and techniques for crop management and/or breeding	14 (20%)	3 (4%)	8 (12%)	14 (20%)	30 (44%)	3.62	1.56	Low perception
Effect on changing sales and marketing behavior	16 (23%)	5 (7%)	8 (12%)	15 (22%)	25 (36%)	3.40	1.59	Low perception
Effect on changing relationship with other farmers	8 (11%)	2 (3%)	6 (9%)	18 (26%)	35 (51%)	4.01	1.33	High perception
Effect on changing your vision for your farm in 10 years	9 (13%)	4 (6%)	7 (10%)	16 (23%)	33 (48%)	3.86	1.41	High perception

SD, strongly disagree; D, disagree; N, neutral; A, agree; SA, strongly agree. *Decision – weighted average = 3.70. Source: Author's elaboration from analysis of field data (2023).

decision-making are key factors, but limited leadership, motivation and engagement challenges, and restricted community group participation hinder women's empowerment. Meinzen-Dick et al. (57) emphasized the importance of integrating gender into agricultural research, development, and extension to enhance food security and promote innovation in developing countries. Gender perceptions can significantly influence smallholder farmers' adoption of resilient or sustainable farming practices. Studies have shown that women, who are often the most vulnerable smallholder farmers, are bound to benefit from this agricultural technology, mostly because of its attributes (i.e., climate smart practices) (58). Additionally, women have less access to productive resources, financial capital, and advisory services compared to men which may explain women's high positive perception of motivation, engagement, and participation in projects' activities (59).

4.5 Farmers' organizations influence in the adoption of innovative farming practices and decision-making change

Table 9 presents the results of farmers' perceptions of the effects of farmers' organizations on changing practices and decisions on the farm. The items in the survey included the effect of farmers' organizations on "changing input purchasing behavior," "changing practices and techniques for crop management and/or breeding," "changing sales and marketing behavior," "changing relationships with other farmers," and "changing vision for the farm in 10 years." The results of the reliability analysis using Cronbach's alpha for a scale composed of the five items show that the average interitem covariance is 1.58, indicating that the items in the scale are positively correlated. The scale reliability coefficient is 0.93, which is considered high and

suggests that the scale has good internal consistency. This means that the items in the scale are measuring the same construct and are reliable for measuring that construct.

The weighted average decision score is the sum of the mean values for the five items, divided by the total number of the items. It was 3.70, indicating an overall positive perception of the effects of farmers' organizations on changing practices and decisions on the farm. The results show that the highest levels of agreement were observed for changing relationships with other farmers and changing the vision of the farm in 10 years. The Kendall W test shows that the five variables presenting the effects of farmers' organization have similar mean ranks, ranging from 2.69 to 3.27 (Supplementary Appendix 4). This suggests a general agreement that all effects hold some importance. However standard deviations are relatively high, indicating variation in perceived importance among respondents. Kendall's Coefficient of Concordance (W) was estimated at 0.064 and statistically significant at 10%, indicating a weak level of agreement in the ranking of effects across respondents. The weak concordance suggests individual differences in how they prioritize these effects. There is not a strong consensus on which effect is most or least important.

The findings are consistent with previous studies that highlighted the significance of behavioral, social, and cognitive factors in influencing farmers' decisions. Spina et al. (60) found that farmers' attitudes strongly influence their intention to adopt, followed by social norms and perceived control. According to Addai et al. (61), the membership in farmer organizations affects the decision to adopt farm technologies by rice farmers in Ghana. The household head's decision to adopt new farming practices such as machinery use and row planting increases upon joining a farmer organization. A scoping review of the literature on farmers' organizations impacts on small-scale producers in sub-Saharan Africa and India found that farmers' organizations, such as

associations, cooperatives, and women's groups, provide services that contribute to income and productivity for small-scale producers (62). Most reviewed studies reported positive impacts on farmer income, but much fewer reported positive impacts on crop yield and production quality. Environmental benefits, such as resilience-building and improved water quality and quantity, were documented in 24% of the studies. The review suggests that farmers' organizations could be integrated into policy by having access to markets through information, infrastructure, and logistical support at the center of farmers' organizations design (62).

To understand if there are any gender disparities in how farmers' organizations shape farm management, a Kruskal-Wallis's test was performed. The Kruskal Wallis test is a non-parametric test that compares the medians of two or more groups, and it is used when the data do not meet the assumptions of normality and equal variances required by parametric tests. Results showed that there were significant differences between the two groups in all five variables ($p < 0.05$) (Supplementary Appendix 5). Specifically, women had higher mean ranks than men in the perception of the farmer organization effect on changing input purchasing behavior, on changing practices, on changing sales and marketing behavior, and on changing their vision for the farm in 10 years. The higher mean ranks for the female group suggest they generally perceived these effects as more important than the male farmers. Men had a higher mean rank only in the perception of the farmer organization effect on changing relationship with other farmers. The overall assessment suggests that, on average, females tend to provide higher ratings for the farmer organization effects on changing practices and decisions on the farm compared to males. However, the variability in responses is higher among males, indicating that there might be more diverse opinions among males. Women could be more aware of the farmer organization roles and influences because of the important gap in productivity, income, and resources that women are experiencing. According to Bello et al. (63), a disparity between men and women with a gender performance gap of about 11% in favor of men, is partially explained by factors such as the men access to improved varieties, membership of farmer-based organizations, extension services, and quantity of seeds sown.

Farmers' organizations play a significant role in influencing the adoption of farming innovative practices and decision-making change. The positive perceptions of the effects of farmers' organizations on changing practices and decisions on the farm, particularly in relation to changing relationships with other farmers and the long-term vision for the farm, underscore the importance of collaborative and supportive networks in promoting sustainable farming practices. However, the lower levels of agreement regarding changing sales and marketing behavior, as well as input purchasing behavior and crop management practices, suggest that there may be specific areas where farmers' organizations could focus on enhancing their support and influence.

4.6 Farmers perception of agroecological transformation

The findings derived from the perception analysis provide valuable information regarding the farmers' perception of

agroecological transformation drivers and barriers. The descriptive analysis of the sample reveals that most of the participants in the study are male farmers, comprising 83% of the sample. In terms of education level, a significant proportion of the participants have completed secondary education (37%), followed by those with a university level of education (20%). The primary activities of the participants are dominated by olive tree cultivation (43%), with field crop cultivation (28%) and livestock farming (14%) also being prevalent. The participants' age ranges from 21 to 72 years, with a mean of 52 years. Land ownership among participants varies widely, ranging from no land to 100 hectares, with a mean of 17 hectares. There is only one young farmer (27 years old) who does not own any land. On average, the participants have 28 years of experience as farmers, and their primary activity contributes about 63% of their income, with some variation across individuals (Supplementary Appendix 6).

Respondents' perceptions about challenges and barriers of adopting agroecological practices are varying from strong agreement to total disagreement. The percentages of respondents for each category, means, standard deviations, decisions, and the ranking of the perceived barriers and motivating factors to the adoption of agroecological practices by farmers are summarized in Supplementary Appendix 7. The highest perceived barriers are the lack of financing and credit opportunities, the lack of encouragement from the government, water shortages, soil erosion, and other environmental problems, the absence of encouraging legislation and laws, the lack of infrastructure and supporting systems, the lack of training on ecological farming, and the lack of production inputs. Improved water conservation and enhanced soil quality are indeed key benefits of the agroecological transition. However, water shortages and soil erosion can still be perceived as barriers due to the initial challenges and adjustments required during the transition process. Despite the eventual benefits, the transition to agroecology may initially pose challenges in adapting to new practices and overcoming existing environmental issues.

Indeed, the most motivating factors perceived by farmers are that agroecological practices contribute to preserving the environment and natural resources, reduce the cost of production, contribute to improved food quality, are compatible with culture and values, contribute to improved production and income, and are compatible with farmers' knowledge and experience. The most motivating items of the agroecological transformation can be the entry points for the transition. However, the respondents agree less with the facts that agroecological practices and activities are compatible with the financial, economic, technical, and logistical capabilities of farmers. These results are confirmed by Kendall's W test. The test has been used to assess the level of agreement among respondents' rankings of various statements related to agroecological practices and their associated motivations, challenges, and barriers. The value of Kendall's W is 0.20 and the p -value is 0.000 (Supplementary Appendix 7). This indicates that there is a statistically significant weak level of agreement among the respondents' rankings of the various statements related to agroecological practices and their associated challenges and barriers. The mean ranks for each statement provide insight into the relative importance or perception of each item. For example, "Agroecological practices contribute to preserve the environment

and natural resources” has the highest mean rank of 21.87, indicating that, on average, respondents ranked this statement as more important or more in agreement compared to other statements. Conversely, “Constraints and complexity of agroecological transition consist of the lack of consumer demand for ecological products” has a lower mean rank of 9.31, indicating that, on average, respondents ranked this statement as less important compared to other statements. The Cronbach’s alpha value is 0.763, indicating an acceptable level of reliability and suggesting a satisfactory level of internal consistency among the items.

4.7 Key driver and barrier factors of the agroecological transformation in Tunisia

Factorial analysis is conducted to understand the structure of the main drivers and barriers of the agroecological transformation considering the current perceptions of the Tunisian farmers. The factorial analysis conducted on 30 factors (items) related to agroecological practices reveals a nuanced understanding of the complexities and challenges surrounding their adoption. The analysis delineates 9 key components (explaining 78% of the total variance), each capturing distinct aspects of the agroecological transition process (Supplementary Appendix 8).

- Component 1: captures financial, and economic considerations, alongside logistical and technical feasibility, that emerge as crucial determinants of this first factor labeled as “*Compatibility with farmers’ capabilities and knowledge and capacity building needs.*” This component also focusses on technical difficulties facing ecological transformation, such as the lack of training, technical knowledge, and experience.
- Component 2: highlights key constraints such as the absence of encouraging legislation and laws, and the lack of government support, the delayed results to enhance incomes and the lack of exchange of experiences and of cooperation between farmers. The second factor more related to the perception of barriers is labeled as “*Political, institutional, and communication barriers and risk perception.*”
- Component 3: includes constraints such as the high cost of transition, difficulties in changing production habits and lack of cooperation between the different stakeholders. This factor is labeled as “*Stakeholder cooperation and implementation challenges.*”
- Component 4: emphasizes the alignment of agroecological practices with cultural and economic expectations, including initial productivity changes, cost reduction, and long-term production and income improvement. This component can be interpreted as “*Cultural and economic benefits.*”
- Component 5: highlights logistical difficulties such as input unavailability, the lack of infrastructure and supporting systems and challenges in scaling up agroecological practices. This factor is summarized as a barrier and labeled as “*Logistical difficulties and scaling-up challenges.*”
- Component 6: focuses on environmental aspects, including the contribution of agroecological practices to preserve the

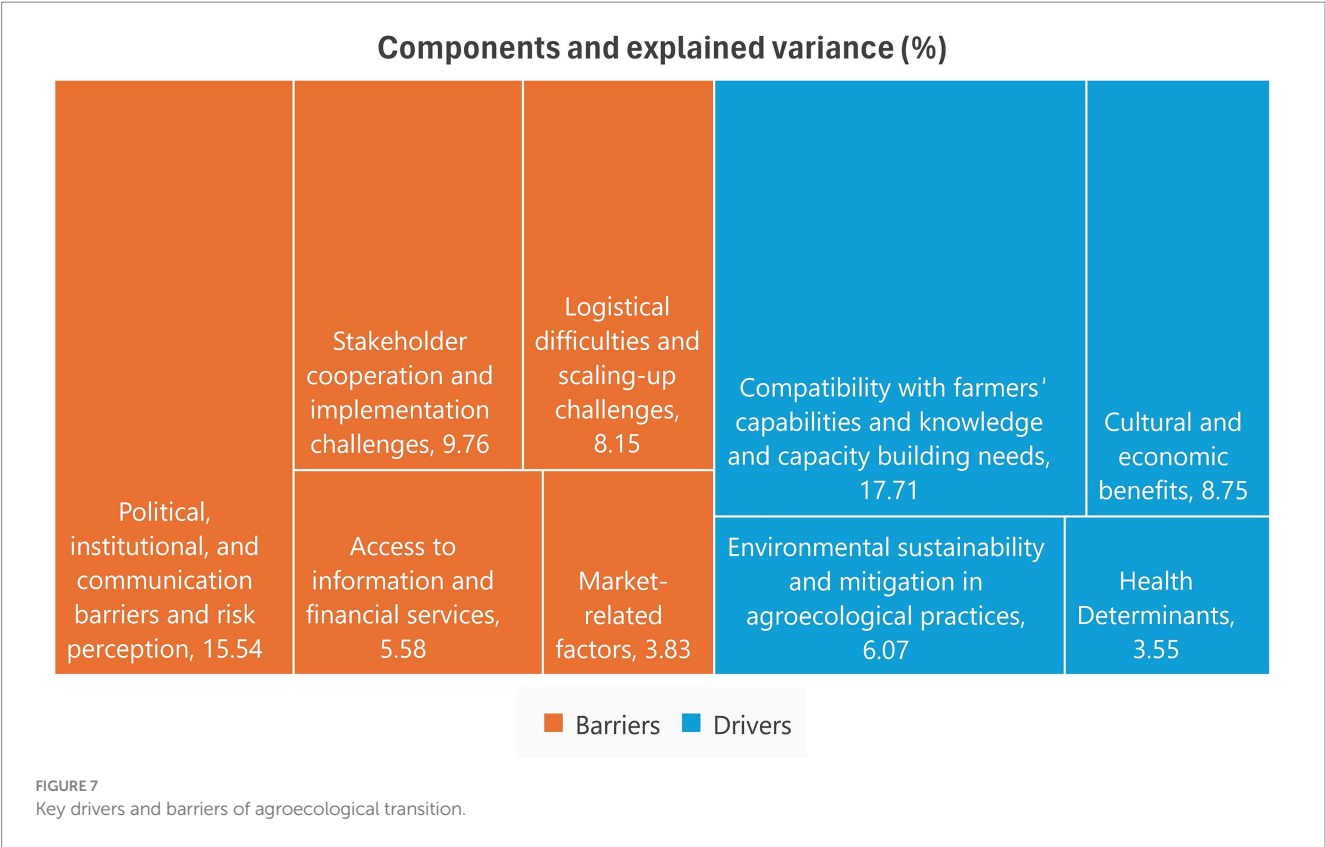
environment and natural resources, and constraints related to water shortages, soil erosion, and other environmental problems. This factor can be interpreted as “*Environmental sustainability and mitigation in agroecological practices,*” highlighting the role of environmental challenges and mitigation factors as drivers of the agroecological transformation.

- Component 7: encompasses factors related to access to both economic and non-economic aspects such as access to information, credit, and financial support. This component considered as a barrier and is identified as “*Access to information and financial services.*”
- Component 8: highlights constraints such as the lack of consumer demand for ecological products, marketing difficulties, and market access challenges. The component is identified as “*Market-related factors.*”
- Component 9: suggests that agroecological practices contribute to improved food quality and hygiene and can be interpreted as “*Health Determinants*” factor.

Figure 7 presents drivers and barriers in agroecological transitions in Tunisia according to the local farmers involved. The total explained variance by the extracted components reached 78%. The drivers include compatibility with farmers’ capabilities (17.71%), cultural and economic benefits (8.75%), environmental sustainability (6.07%), and health determinants (3.55%). Political, institutional, and communication barriers (15.54%), stakeholder cooperation challenges (9.76%), logistical difficulties (8.15%), access to information and financial services (5.58%), and market-related factors (3.83%) are identified as barriers. Consistent with these results, the literature highlights the complexity of the factors involved as barriers of agroecological transitions (64). Furthermore, the sustainability of transitions to agroecology is linked to factors such as capacity building, social capital, and farmer knowledge, emphasizing the multifaceted nature of these transitions (65).

5 Conclusion and implications

In examining the potential for agroecological transitions in Tunisia, specifically the Kef-Siliana transect, this study has revealed valuable insights. The SWOT analysis demonstrates that farmer organizations have clear goals, diversified farming systems, and partnerships in collaboration with various organizations and institutions. The study emphasizes the significant potential of these farmers’ organizations in advancing sustainable farming practices. However, it also underscores the need for targeted efforts to address specific challenges in farming practices and decision-making. Outlined obstacles include the unavailability of seeds and fertilizers, water shortage, limited income, diseases, and marketing issues. To prioritize value chains for agroecological transition in Tunisia, the study identifies the olive oil sector as the most promising for development, considering economic, social, and environmental factors. Implementing recycling and input minimization principles in the olive oil supply chain and bridging the gap between theoretical agroecological concepts and farming practice implementation are recommended to cultivate sustainable



agroecological farming systems. The survey’s results indicate that farmers who received training and assistance with agroecological practices reported positive changes in their ideas and practices. Therefore, the study emphasizes the importance of farmer engagement, knowledge production, and multi-stakeholder collaboration in promoting agroecological transitions in Tunisia. The Bayesian Belief Network (BBN) visualization highlights complex interdependencies between different factors, emphasizing the significance of women’s participation, improved services and contracts with farmers’ organizations, and a better understanding of farming practices to facilitate agroecological transitions. The study identifies various challenges and barriers, including political, institutional, and communication barriers, logistical difficulties, and market-related factors. To address these challenges and facilitate agroecological transitions, the study emphasizes the need for farmer engagement, knowledge production, and multi-stakeholder collaboration. Furthermore, it suggests targeted efforts to address specific aspects of farming practices and decision-making. The study’s findings also underscore the influence of gender perceptions on the adoption of resilient and sustainable farming practices among smallholder farmers, emphasizing the importance of integrating gender into agricultural research, development, and extension to enhance food security and foster innovation in Tunisia. At the political and institutional level, the study recommends the increase of public incentives and supportive legislation to support agroecological practices. Additionally, the study suggests offering innovative financing and credit opportunities to farmers to overcome the lack of production inputs and limited access to microfinancing. Recognizing the lack of training on ecological farming as a

significant barrier, the study proposes the development of capacity building programs to equip farmers with the necessary knowledge and skills to embrace agroecological practices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans because the farmers participated voluntarily and provided their consent to answer the survey questions. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AS: Conceptualization, Formal analysis, Methodology, Writing – original draft, Data curation, Investigation, Software. BD: Conceptualization, Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing, Project administration. AO: Validation, Writing – review & editing. RM: Data curation, Investigation, Writing – original draft. AF: Funding acquisition, Project administration, Resources, Writing – review & editing. MZ:

Investigation, Writing – review & editing. MD: Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2024.1389007/full#supplementary-material>

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From acute food insecurity to famine: how the 2023/2024 war on Gaza has dramatically set back sustainable development goal 2 to end hunger

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The widespread destruction and the devastating humanitarian toll caused by the ongoing war on Gaza have transformed this besieged Strip into a place of death and despair. This review will explore the implications of this war for food security, focusing on Sustainable Development Goal (SDG) 2, which seeks to fight malnutrition and food insecurity and achieve zero hunger by 2030. This work is based on a review of grey literature, such as reports from government and non-governmental agencies, as well as recent scientific journal publications. Our results show that the ongoing war on Gaza has exacerbated the already acute food insecurity that Gazans have been struggling with since the blockade was imposed in 2007. Restless bombardment and ground operations have damaged or even razed agricultural land and all food production infrastructure (such as bakeries, mills, and food processing facilities), destroying Gaza's food system. Facing catastrophic levels of hunger, some families, especially in northern Gaza have recently been resorting to eating animal feed and weeds to survive. With the starvation of civilians being used as a method of warfare, many experts and human rights organizations argue that Gaza is now the world's worst hunger crisis and its population is on the verge of famine, if not already there. Moreover, this unprecedented humanitarian crisis in Gaza could have significant consequences on global food security in its six pillars, jeopardizing the implementation of SDG 2. While international organizations are making efforts to mitigate the catastrophic food shortage and famine, more comprehensive and sustainable solutions are needed to address the root causes of food insecurity in Gaza and ensure that all residents have access to an adequate and nutritious diet.

KEYWORDS

food security, malnutrition, food shortage, sustainability, SDG 2, starvation war, weaponizing food

1 Introduction

According to the Food and Agriculture Organization (FAO) and other international agencies, food security refers to physical, social, and economic access to sufficient, safe, and nutritious food for all people at all times (FAO et al., 2020). To achieve food security, six pillars, namely availability, access, utilisation, stability, agency, and sustainability should be fulfilled simultaneously (Farcas et al., 2020; HLPE, 2020; Boyacı-Gündüz et al., 2021; Ben Hassen and El Bilali, 2022). Food security is central to the global development agenda and Sustainable Development Goals (SDGs), particularly SDG 2, which plays a crucial role in achieving zero hunger by the year 2030, with food security being an intrinsic component of it. SDG 2 is key to the success of the achievement of the entire SDGs due to its close interlinkage with society, economy, and the environment (Gil et al., 2019; Chen et al., 2023). SDGs offer some hope to driving sustainable solutions to problems, such as food insecurity. However, despite considerable efforts to end hunger over the last few years, which has led to slight improvements in some countries, the overall number of people facing high levels of acute food insecurity is on the rise again in many regions of the world, due mainly to armed conflicts (GRFC, 2023).

Food insecurity is a situation when people lack secure access and agency over sufficient amounts of safe and nutritious food that is necessary for normal growth and development of human beings (HLPE, 2020; GRFC, 2023). Food insecurity is one of the most pressing challenges facing humanity today, especially with the growing outbreak of pandemics and armed conflicts, and wars, which are widely recognised as the main contributors to food insecurity in various parts of the world. Particularly the COVID-19 pandemic and the Russia–Ukraine conflict have been extensively explored in recent studies, showing that these two extraordinary crises have been the most important drivers of food insecurity globally (Béné et al., 2021; Jagtap et al., 2022; Barakat et al., 2023; Mhlanga and Ndhlovu, 2023; Xu et al., 2023).

Many scholars and international organizations have developed various indicators to measure food insecurity. For example, integrated food security phase classification (IPC) is a global standard for the classification of food insecurity, and provides a common scale for measuring the severity of food insecurity. According to the IPC scale (Figure 1), acute food insecurity is classified into five phases, namely no/minimal for phase 1, stressed for phase 2, crisis for phase 3, emergency for phase 4, and catastrophe/famine for phase 5. Besides acute food insecurity, the IPC is used also to provide decision-makers with invaluable information about chronic food insecurity and acute malnutrition, making it a landmark in the fight against global hunger. Each phase is linked to priority response objectives for action, noting that phase 3 or worse requires urgent action. The IPC scale is commonly used by the international community to determine whether a famine is happening or likely happening in a country or a region (IPC, 2017, 2023).

The region located along the Eastern Mediterranean coast has frequently suffered from political instability and conflicts that have compromised food security and increased malnutrition (Al-Jawaldeh and Meyer, 2023). Particularly the Gaza Strip, a small and densely populated region in the Middle East, has been witnessing several hostilities and escalations of violence since the siege of Gaza began in 2007. Gaza has been blockaded for more than 16 years, with its

borders, economy, movement of people and goods, electricity, other vital resources being controlled by Israel, which has led to many food security, undernutrition, and associated health complications (El Kishawi et al., 2017; Albelbeisi et al., 2018; Abu Hamad et al., 2022). The UN once predicted that Gaza would be uninhabitable by 2020, and the urgent need to address challenging issues in Gaza, such as the unsuitability of 95% of Gaza municipal well water for human consumption and the problem of food insecurity, has been highlighted even before the outbreak of the current war (Al-Shalalfeh et al., 2018; Nassar et al., 2023).

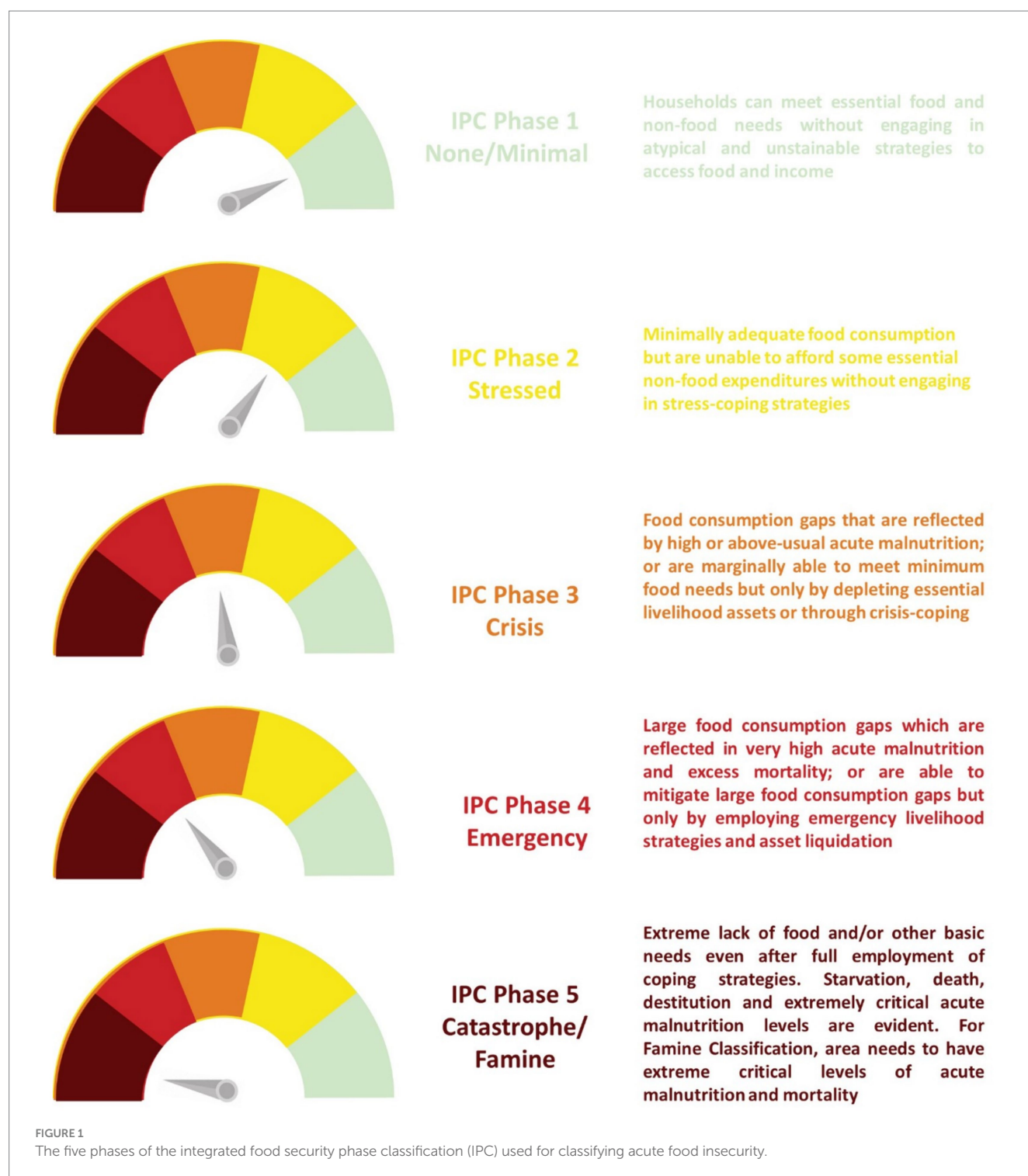
Since October 2023, the Gaza Strip has experienced one of the world's worst recent food crises due to the ongoing war. Indeed, many independent experts and advocacy organizations have warned that the tight blockage, forced displacement, and restless bombardment of buildings and facilities, including food production infrastructure are increasing the risk of shifting the food situation in the besieged Strip from acute food insecurity, due to decades-long blockade, to famine. According to the latest IPC report (covered up to 7 February), the entire population (2.2 million people) has been experiencing high acute food insecurity, with one out of four people being in the catastrophe phase (Bilukha et al., 2023; ESCWA, 2023; GRFC, 2023; Agha et al., 2024; IPC, 2024b).

This study aims to conduct a scoping review of various sources (including peer-reviewed journal publications and grey literature) to highlight the potential implications of the ongoing starvation war on Gaza for both food security and food sustainability, focusing on SDG 2. The rest of this manuscript is organised as follows: After giving a general overview of SDG 2 (Section 2) and food security in Gaza before the ongoing war (Section 3), our study will show the impact of the ongoing war on Gaza on food security (Section 4). Examples of food weaponisation and the impact of the current war on SDG 2 will be shown in Section 5 and Section 6, respectively. In Section 7, we will discuss the potential global food security crisis that could be triggered by the escalation and repercussions of the war, while mitigation measures and recommendations will be suggested in Section 8. Finally, implications and limitations of this study will be given in Section 9 and conclusions will be drawn in Section 10.

2 General overview of sustainable development goal 2 to end hunger

About 9 years ago, the UN member states adopted a new agenda composed of 17 SDGs, including SDG 2, which seeks to create a world free of hunger in all its forms by 2023, achieve food security and improved nutrition, and promote sustainable agriculture. The targets of SDG 2 are mainly related to food security, agriculture sustainability, market, and agricultural investments (Gil et al., 2019; Otekunrin et al., 2019). The 8 targets of SDG 2 have been summarized in Figure 2.

While only 6 years remaining until the attainment of this ambitions goal, FAO reports and other sources, as well as recent publications demonstrate that reaching zero hunger in the coming few years will be a challenging task (FAO et al., 2020; Chen et al., 2023; Otekunrin, 2023). Recent estimates show that hunger is on the rise in many parts of the world, and it is still affecting between 690 and 783 million people in the world, with 24% of the population in Africa, 12.6% in Latin America and the Caribbean, and 9.7% in Asia being faced with severe food insecurity. By 2015, 7.6% of the world's



population found themselves in a state of severe food insecurity, while severe food insecurity raised to 11.3% in 2022 (FAO, 2023), which underscores the severity and the growing complexity of this crisis.

Achievement of the “zero hunger” goal is affected by various socioeconomic factors, including among others, pandemics, conflicts, climate change. However, the achievement of this goal is essential for the success of the other SDGs, especially SDG 1 (no poverty) and SDG 3 (health and well-being) (Arora and Mishra, 2022; Chen et al., 2023).

3 Pre-October 2023 food security in Gaza

The issue of food security in Gaza has been a longstanding concern influenced by various socio-political factors, with the Israeli blockade being a significant contributor. This section aims to explore the food security situation in Gaza before October 2023. The Gaza Strip, characterized by dense population, has dealt with economic and humanitarian challenges for decades.

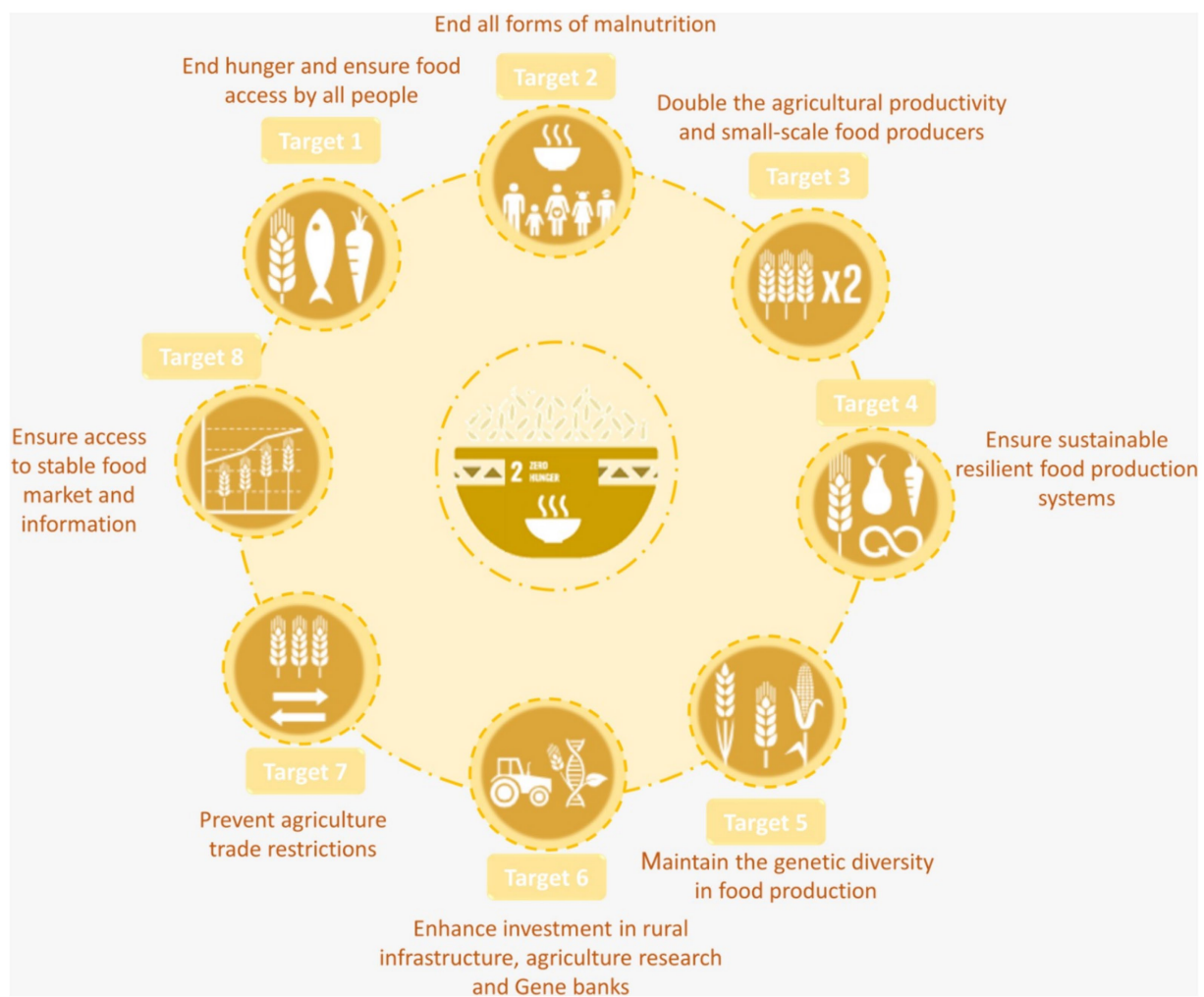


FIGURE 2
Sustainable development goal 2 (SDG 2) that seeks to end hunger by 2023.

Since 2007, Israel has enforced a stringent blockade on Gaza, severely limiting the movement of goods, including food and agricultural inputs, resulting in a dire humanitarian crisis. The blockade has brought profound effects on Gaza's economy, infrastructure, and social fabric. Import restrictions have sharply curtailed access to essential food items, leading to shortages, price escalations, significantly impacting food security. According to UNRWA, food security in Gaza has worsened significantly following the 2007 blockade, with 63% of individuals in the Gaza Strip experiencing food insecurity and relying on international aid. Ongoing political divisions among Palestinians further escalated the humanitarian and service delivery challenges on the ground. With 81.5% of the population living below the poverty line and an overall unemployment rate of 46.6% (48.1% for Palestinian refugees residing in camps) as of the third quarter of 2022, along with a youth unemployment rate of 62.3% (15–29 years, refugees, and non-refugees), the already precarious humanitarian situation in Gaza has been at risk of further deterioration. Access to essential services, such as clean water and electricity has been at crisis levels, significantly impacting various aspects of daily life. For instance, clean water was inaccessible to 95% of the population, exacerbating health risks.

Electricity availability averages around 11 h per day as of July 2023, but persistent power shortages severely disrupted essential services, particularly in healthcare, food production, water, and sanitation. Furthermore, these challenges continued to undermine Gaza's fragile economy, particularly affecting manufacturing and agriculture sectors. Urgent action was required to address these pressing issues and alleviate the suffering of Gazan residents. In other words, the economy has been devastated, resulting in widespread impoverishment and hindering the development of a highly skilled and educated society (UNRWA, 2023).

Preceding October 2023, Gaza was already confronting a humanitarian crisis, with a sizeable portion of its population dependent on food assistance. As per the United Nations, over half of Gaza's populace has experienced food insecurity, lacking access to a sufficient and nutritious diet. Alarming, malnutrition rates, particularly among children, has soared. According to Albelbeisi et al. (2018), at 6 months of age, the occurrence of underweight and stunting stood at 5 and 9%, respectively. However, by the time the children reached 24 months, these figures shifted to 4% for underweight and 20% for stunting. Wasting was most prevalent at 6 months, with a rate of 10%, but decreased notably to 3% by 24 months. Notably, a higher proportion

of girls exhibited stunting at 9, 12, and 18 months, underweight at 24 months, and wasting at 12 months. Early growth retardation in terms of length was more pronounced compared to weight, with stunting observed in one-fifth of boys and girls by the age of 2.

Constrained access to nutritious food has created a surge in malnutrition-related health complications, encompassing growth stunting, micronutrient deficiencies, and chronic ailments. The prevalence of low birth weight, as reported by the Palestinian Central Bureau of Statistics, was 10.7 nationally (11.8 West Bank, 9.1 Gaza Strip) between 2019 and 2020 (Assaf et al., 2023). Exposure to war and occupation in Gaza was associated with an increased prevalence of low-birth weight (Palestinian Central Bureau of Statistics, 2021). Several research studies were carried out in the Gaza Strip in this regard. Tsigga and Grammatikopoulou (2012) noted in their comprehensive study review that the prevalence trends of underweight and wasted children in the Gaza Strip showed a slight decrease after 2004. Albelbeisi et al. (2018) reported that stunting affected one-fifth of boys and girls by the age of 2, with girls exhibiting a higher prevalence compared to boys. El Kishawi et al. (2017) identified in their study that short maternal stature and parental consanguinity were linked to stunting in the Gaza Strip. Al Najjar and Al Shaer (2022) highlighted additional risk factors such as inadequate awareness of healthy diets, poverty, unfavourable socioeconomic conditions, urbanization, and lifestyle among communities. Furthermore, the political landscape and the blockade in the Gaza Strip were found to be associated with all the aforementioned risk factors (Radi et al., 2013). In the Gaza Strip, the prevalence of anaemia among secondary female students older than 15 years was 33.5 and 31% among women of reproductive age in 2019 (WHO, 2021).

Before the ongoing war, Gaza's food security situation was already risky, highly likely to be attributable to the long Israeli blockade. This blockade has stifled economic activity, disrupted food distribution networks, and worsened poverty and vulnerability among Gazan residents. Effectively addressing the underlying causes of food insecurity in Gaza necessitated the lifting of the blockade, fostering sustainable economic development, and ensuring uninterrupted access to vital humanitarian assistance and services. In the absence of interventions pre-October 2023, the humanitarian crisis in Gaza has been poised to escalate.

4 Impact of the ongoing war on Gaza on food security

The ongoing war on Gaza has led to severe food crisis (Figure 3), significantly impacting food security in its six pillars (i.e., availability, access, utilisation, stability, agency, and sustainability). Many recent reports show that the population of Gaza is at immediate risk of famine, if not suffering it already (IPC, 2024a; ReliefWeb, 2024a; FAO, 2024b).

4.1 Food availability

The physical food availability concerns the “supply side” of food security, covering aspects related to measurements of food production, stock, and net trade (de Oliveira Veras et al., 2021). Wars and armed conflicts can adversely impact food security through military operations that interfere with food production, storage, and mobility

in the war zone (Ben Hassen and El Bilali, 2022; Halmaghi et al., 2023; Béné et al., 2024). In the current war on Gaza 2023–2024, all of Gaza is a war zone, and every part of the Gaza Strip is affected by hostilities, carpet bombing, and shelling, destroying residential buildings, hospitals, schools, roads, transport means, and food production systems (including both plant crops and animal livestock). According to available data, 28% of cropland and more than 70% of fisheries have been destroyed (Anera, 2024) (Figure 4).

Food is far from being available in Gaza, and the situation only deteriorates with time. The war on Gaza has further damaged food availability by disrupting imports of all food and non-food items vital for food schemes, such as fuel and supplies required for agricultural production (FAO, 2024b). The war on Gaza was announced with an explicit intention to cause food insecurity in Gaza, since on October the 8th, 2023, Israel officially declared its intention to deprive Gaza of food, water, and energy (Human Rights Watch, 2023). Water and energy are interconnected with food for the provision of food security. The access to these three basic necessities (i.e., food, water, and energy) has been weaponised in the current war on Gaza (ESCWA, 2023).

The besieged Gaza was denied food supply from the crossings that connect it to the outer world. When families in the Gaza Strip were forced to leave their homes and towns and flee northern Gaza, they were not provided with food, means of transport, water, or shelter. Those who stayed in the north had their bakeries, flour stores, and food markets bombed. In previous researched wars in Gaza, receiving humanitarian aid resulted in better access to basic services and social safety nets, highlighting the significance of quick short-term humanitarian response in supporting the resilience capacity of households in Gaza (Brück et al., 2019). However, victims of the current war are suffering from impediments of humanitarian aid from entering the Gaza Strip (Human Rights Watch, 2023), not to mention reaching households and refugee camps. This has led to catastrophic levels of food insecurity in Gaza. As of 7 February 2024, 100% of Gaza population were already in Phases 3 and above, 53% in phase 4, while 26% in phase 5 (catastrophe) (IPC, 2024b).

4.2 Access to food

Physical and economic access to food focuses on guaranteeing household-level food security, considering sufficient food access, markets, and prices (The World Bank, 2023b). The consequences of war on food security are diverse, encompassing physical destruction and disruptions in trade and value chains (Messer and Cohen, 2015; Lin et al., 2022; Nguyen et al., 2023).

Agriculture plays an important role in the economy of the Gaza Strip and is part of the availability and accessibility dimensions of food security, including production, stocks, and net trade (Halmaghi et al., 2023; The World Bank, 2023b). Agricultural harvest, herds, and fish are the main food sources in the Gaza Strip for food security and export revenue (FAO et al., 2023). The main agricultural land is located in north and east Gaza, especially near Khan Younis. Most of the farms in this area have been destroyed, and Palestinians were impeded from safely reaching their land and harvesting their crops from the areas that survived the attacks. Many households all over the Gaza Strip grew fruits and vegetable crops in their homes. The carpet bombing and shelling and setting of explosives in houses have led to losing shelter, life investments, and food security (Buheji and Hasan, 2024).

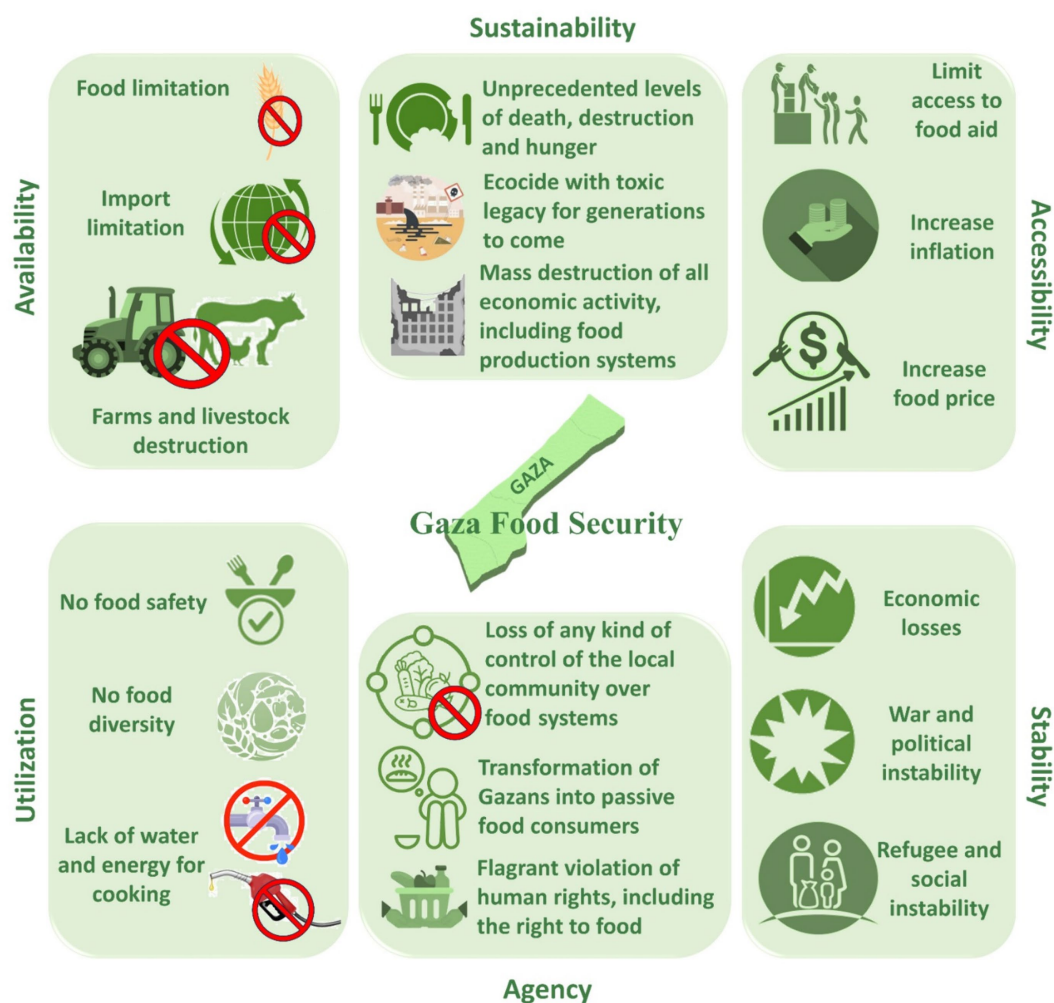


FIGURE 3
The impact of the ongoing war on Gaza on the six pillars of food security.

During the first 5 months of this war, Gazans have been suffering from severe starvation, especially in northern Gaza where people have started dying of hunger in February and early March 2024. At the same period, [ReliefWeb \(2024a\)](#) reported the death of 15 children due to malnutrition at only one hospital (Kamal Adwan Hospital) in Gaza City and severe cases of starvation-related illnesses among children, indicating the existence of famine in Gaza. FAO predicted earlier that thresholds for acute malnutrition and non-trauma mortality may also be breached by mid-2024 if hostilities continue ([FAO, 2024b](#)).

Economic access to food is hindered by inflation in food prices combined with low or no household purchasing power, making the limited available quantities of food unaffordable for most households. For example, between September and November 2023, wheat flour and rice prices increased by about 50%, while vegetables increased by almost three times ([Figure 5](#)).

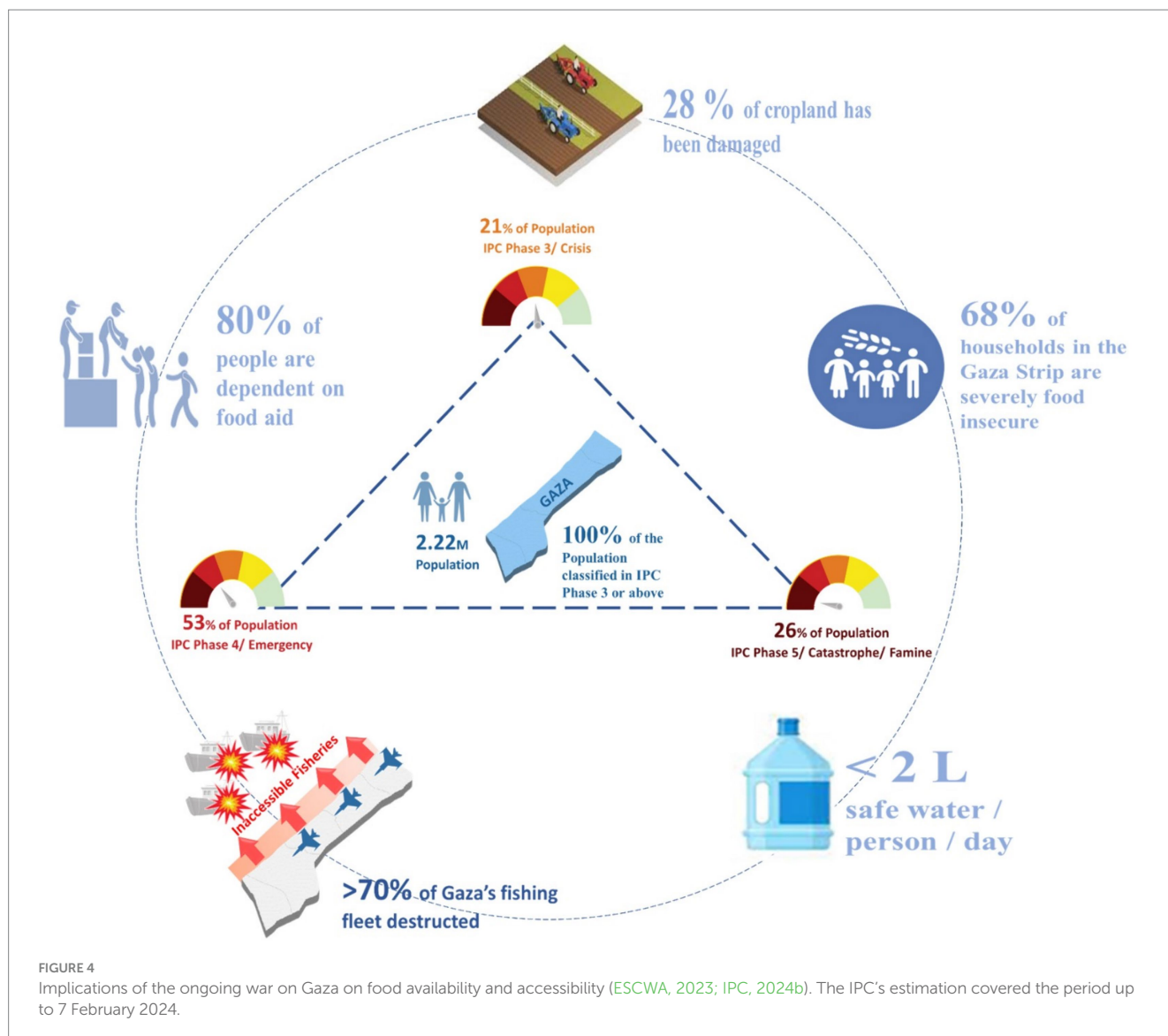
Almost at the same period, the prices of olive oil and chicken meat increased by 65% and about 90%, respectively ([WFP, 2023](#); [FAO, 2024a](#)). Economic access to food is further constrained by a sharp decrease in incomes with the loss of jobs due to the war and the destruction of almost everything. Already in December 2023, it was

estimated that economic activities and employment had declined by 85% since the beginning of the hostilities ([The World Bank, 2023a](#)).

During crises, achieving food security needs effective approaches to balance the food, the affected population needs, food safety, food producers, food supply and distribution chain, the economic situation, and managing waste ([Farcas et al., 2020](#)). In the case of Gaza, the world failed to achieve the first item of providing enough food for people under physical siege with no means to import or produce food, meaning that the first two pillars of food security have not been addressed. Hostilities involving aerial bombardment, ground operations, and population-wide besiegement have resulted in extremely high-levels of acute food insecurity, where 85% of Gazans have been forcefully displaced to concentrate in Rafah (only 64 square kilometers), which is now massively overcrowded with around 1.9 million civilians.

4.3 Food utilisation

Food utilisation is the third dimension of food security and refers to the nutritional status of individuals related to feeding practices and



good care, including preparation, diversity, food safety, and fair intrahousehold food distribution (El Bilali et al., 2019; FAO, 2022). The ongoing war on Gaza has significantly jeopardised the food utilization pillar of food security. Indeed, as availability and access to food have been disrupted due to the ongoing war, hunger has become widespread in Gaza, especially among the most vulnerable population. Therefore, driven by extreme hunger, people scour the streets for anything to eat to survive, and aspects related to food safety and diversity have become less relevant or even obsolete for hungry families. A recently published report by humanitarian group Refugees International confirms that the conditions inside of Gaza are disastrous, highlighting the fact that famine-level hunger is rampant among Gazans (Refugees International, 2024).

Food utilisation has also been affected by a lack of safe water that can be used for drinking and food cooking, due to fuel unavailability, as most of Gaza's water is supplied from wells and underground aquifers requiring fuel for extraction and desalination. It is reported that the local population only has access to less than 2 liters of safe water per person per day for drinking and domestic hygiene (Bilukha et al., 2023).

Besides the issues related to food safety and diversity as well as limitation of safe water, another example that shows the severe disruption of the physical utilization of available and accessible food in Gaza is the restrictions imposed on cooking gas. Indeed, because of the lack of cooking gas, many reports show that Gazans have been forced to rely on burning firewood and wood rubbish, further complicating the utilization of available food (IPC, 2024b).

4.4 Food stability

Food stability concerns the sustainability of the three other dimensions (i.e., availability, access, and utilisation) over time, ensuring adequate food intake throughout life (Lin et al., 2022; Halmaghi et al., 2023; Rabbi et al., 2023). The intensive bombardment and ground operations have made the situation in Gaza extremely volatile, with absence of any stability to access to food and other basic necessities and services. Unemployment and food price inflation are among the main economic contributors to instability of food security in the Gaza Strip (Bilukha et al., 2023; European Commission, 2024).

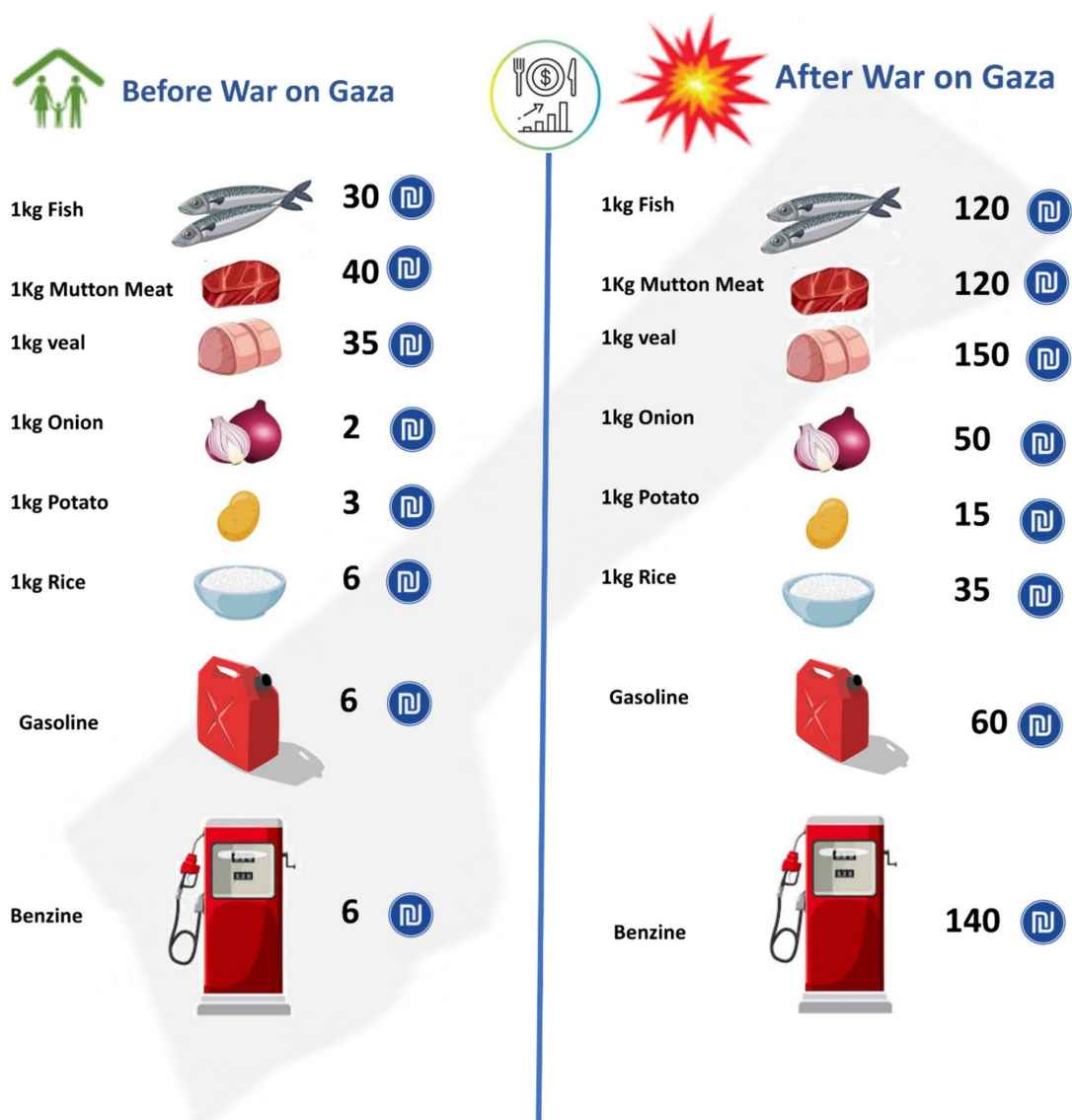


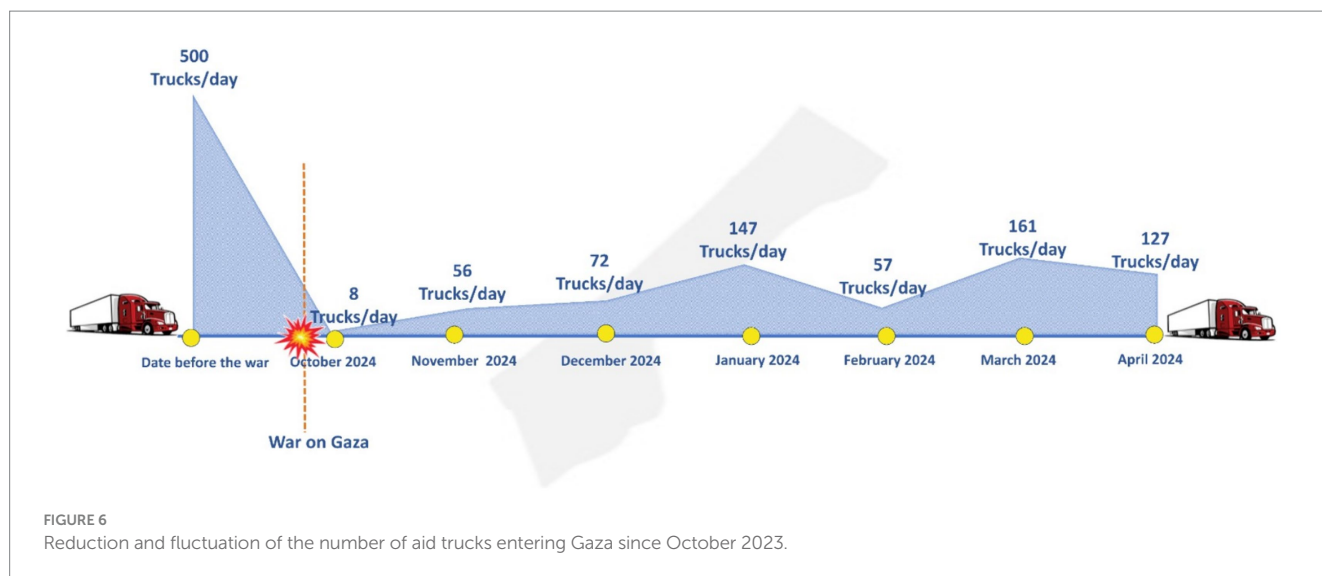
FIGURE 5

Prices of some of food items before and during the ongoing war on Gaza (prices are expressed in Israeli shekel₪, which is the currency of Israel and in the Palestinian territories of the West Bank and the Gaza Strip).

Another crucial factor that is compromising the stability pillar of food security is irregular humanitarian food aid provision. Indeed, now the entire population in Gaza has become dependent on humanitarian aid for their survival, while access to aid has been totally controlled by the occupation military. Food trucks of essential life-saving food commodities are queueing outside Rafah, waiting for clearance. Each food truck must be subjected to arbitrary Israeli inspections slowing aid delivery and reducing the rate of trucks entering into Gaza. At least 500 food trucks were entering Gaza before the outbreak of the ongoing war. Instead of increasing the number of trucks due to demolishing food production in Gaza, this has been decreased significantly (Figure 6). According to the UNRWA figures, only 8, 56, and 72 trucks per day were allowed to enter Gaza in October, November, and December 2023, respectively. An average of 147 trucks was entering Gaza daily in January 2024, while this was even dropped to only 57 trucks in the second and third weeks of

February after the ICJ ruling was announced, in clear incompliance with the issued provisional measures (OHCHR, 2024). In March and April 2024, the number of aid trucks entering Gaza was risen slightly as an average of 161 and 127 crossed into Gaza per day via Kerem Shalom and Rafah land crossings (UNRWA, 2024; ReliefWeb, 2024a,c).

Additionally, allegations have been raised by Israel concerning the participation of staff of UNRWA in the 7 October 2023 attack. Many countries have frozen their funding to this UN agency dedicated to Palestinian refugees, which have raised alarm for aggravating the humanitarian crisis of Palestinians in Gaza who have been already facing dire food, water, and medical shortages. Besides its direct disastrous impact, the ongoing war on Gaza is expected to have negative consequences on long-term food security due to soil degradation and contamination, and the destruction of agricultural land and food facilities. The loss of productive farmland not only



threatens the immediate food supply but also hinders the region's ability to recover and rebuild its food system after the war (UNCTAD, 2024).

4.5 Agency

It has been recently suggested that agency and sustainability should be formally recognized as dimensions of food security in food policy frameworks (HLPE, 2020; Clapp et al., 2022; Mockshell and Nielsen Ritter, 2024). Agency refers to “the capacity of individuals or groups to make their own decisions about what foods they eat, what foods they produce, how that food is produced, processed and distributed within food systems, and their ability to engage in processes that shape food system policies and governance” (HLPE, 2020). Béné and Devereux (2023) argued that greater attention must also be paid to agency and food sovereignty as emerging elements of food security, while Clapp et al. (2022) considered agency as an important aspect of addressing inequities and power imbalances within food systems.

The current war on Gaza has damaged and destroyed food production facilities and systems, making people in Gaza completely dependent on the entry of humanitarian assistance. This has led to the destruction of the capacity for Gazans to make any meaningful decision about and participate in food systems on their own terms in ways that allow them to be free from hunger and its associated deprivations. The agency pillar of food security requires engaged consumers to become active food citizens (Clapp et al., 2022), but the total blockade imposed by Israel has transformed the people in Gaza into passive food consumers. It is widely recognized according to the agency pillar that the local community (i.e., in this case, the inhabitants of the Gaza Strip) has the right to self-determination in any political and policy discussion that could affect their livelihoods or food systems. However, many discussions have been around over the last few months regarding the future of Gaza between Israeli and several regional and international actors but without any involvement of Palestinian communities. Moreover, the concept of agency is closely related to human rights, including the right to food (HLPE, 2020). Nonetheless, massive violations of these fundamental rights have been

repeatedly reported by Human Rights Watch and other non-governmental organizations, pointing out the struggle of the Palestinian population for land and food sovereignty (Human Rights Watch, 2023, 2024; CETIM, 2024).

4.6 Sustainability

Food sustainability can be defined as “the long-term ability of food systems to provide food security and nutrition today in such a way that does not compromise the environmental, economic, and social bases that generate food security and nutrition for future generations” (HLPE, 2020). The current war on Gaza has dramatically affected food sustainability in its 3 dimensions (i.e., social, economic, and environmental) in various ways.

From a social point of view, this war has led to catastrophic impacts on food sustainability due to unprecedented levels of death, hunger, and poverty for present and future generations in Gaza. Since the onset of the current war, Gaza has suffered unprecedented destruction of all food production facilities, including agriculture and fishing and related food processing and distribution. Besides the direct consequences on food security of the people of Gaza, such mass destruction will compromise the ability of the Palestinian food system to feed future generations. Destruction of agricultural assets and food infrastructure as well as soil and land contamination and degradation have extremely limited the functionality of the food system in Gaza, requiring large-scale investment and considerable time before recovery. From economic perspectives, the widespread destruction of farms, livestock, and other producing food facilities in Gaza has caused disastrous consequences on food systems and Gaza's economy that will likely take decades for Gaza to return to pre-October 2023 welfare levels (Nassar et al., 2023; UNCTAD, 2024).

Moreover, the environmental destruction caused by the current war on Gaza has been devastating to the point that it has been described as an ecocide (Fontaine, 2024). Growing evidence shows that this war is a serious contributor to huge environmental harm because of the widespread use of chemical warfare, such as white phosphorus and other toxic chemicals and explosives. Many reports

show that air, soil, and water pollution, as well as biodiversity loss and other potential ecological damages, are irreversible and irreparable consequences of the ongoing war, exacerbating Gaza's vulnerability amid climate change. This war is expected to leave a toxic legacy for generations to come due to the severe long-lasting damage to the environment and the resulting long-term consequences on human health and ecosystems (Fontaine, 2024; Pearce, 2024). Similar consequences of sustainability have been recently reported on others wars, such as the war in Ukraine (Pereira et al., 2022; El Bilali and Hassen, 2024).

5 Examples of food weaponisation

There is growing evidence showing that food is weaponised against civilians in Gaza. Indeed, Gazans have been starved since the beginning of this war, and those seeking humanitarian convoys have been systematically targeted by bombing raids or missile attacks. Human Rights Watch and other human rights groups and organisations have reported that Israel is using starvation of the people of Gaza as a method of warfare by attacking all food facilities necessary for the survival of the civilian population, such as bakeries, flour stores and mills, food storage facilities, and food market infrastructure. According to many references and experts, the destruction of Gaza's food producing systems and imposing restrictions on food aid entering Gaza (especially in northern Gaza where thousands of people have been facing extreme food shortages for months) are typical features of food weaponisation and using starvation of civilians as a method of warfare (ESCWA, 2023; Human Rights Watch, 2023; Hanbali et al., 2024; Refugees International, 2024; ReliefWeb, 2024b; FAO, 2024c).

One of the clearest examples of food weaponisation was shown in February 2024 when around 1,000 innocent unarmed civilians seeking food from aid trucks were killed and injured in northern Gaza. This so-called "flour massacre" was condemned by the United Nations and many countries since images of white flour mixed with the blood of those who gathered in the hope of being saved from starvation shocked the world. Other similar incidents of attacking civilians while waiting for humanitarian aid have been repeatedly reported in March 2024 along the Gaza Strip (OHCHR, 2024). For example, on 1 April 2024, an Israeli drone fired at a convoy belonging to the World Central Kitchen, killing seven humanitarian aid workers (BBC, 2024a).

The international community is providing urgent assistance to Gaza and has been pressuring Israel to facilitate the transfer of more aid into the enclave. However, only a few trucks have managed to reach Gaza, especially the northern part of the Strip. Facing catastrophic levels of hunger, many sources reported that some families, especially in northern Gaza are resorting to eating animal feed and weeds to survive (Euro-Med Human Rights Monitor, 2024; BBC, 2024b). To alleviate the starvation of civilians in Gaza, many countries have been looking for ways to deliver food supplies by sea and air, but hurdles remain in getting food to its starving population. Indeed, serious concerns were raised about delivering food and other essential resources by air when five Palestinians were killed and 10 injured in March 2024 by aid airdrop after a parachute landing a humanitarian airdrop failed to open (The Guardian, 2024a). Currently, plans are being prepared to build a temporary port off Gaza's coast to increase and accelerate deliveries of humanitarian aid. However, many

argue that this would not be an effective solution to the urgent aid crisis in Gaza due to the time needed to set up the port (about 2 months) and the fear of using it as a control point and later evacuating Gaza from its population by encouraging the "voluntary emigration" of residents of the Strip.

6 Impact of the ongoing war on Gaza on SDG 2

The negative impact of wars and armed conflicts (such as the war in Ukraine) on sustainability with its three pillars, the social, economic, and environmental dimensions has been abundantly explored and demonstrated in various recent publications (Pereira et al., 2022; Chishti et al., 2023; da Costa et al., 2023; Neik et al., 2023; Béné et al., 2024). Food security remains a global challenge that is aligned with several SDGs, including SDG 1—No Poverty, SDG 2—No Hunger, SDG 3—Good Health and Well-Being, SDG 13—Climate protection, and SDG 15—Life on land (Pandey and Pandey, 2023). Particularly, SDG 2 is closely related to food security. The ongoing war on Gaza has significantly pushed back all the targets of SDG 2 that aims to achieve zero hunger by 2023.

Farming and fishing stakeholders are particularly vulnerable to food insecurity and have been highly affected by the ongoing war due to the mass destruction of agriculture and aquaculture exploitations and harvests. Even during the very early stage of this war (on 17 November 2023), satellite data showed that the war caused extremely heavy damages and losses in farmland and agricultural infrastructure, livestock, fisheries, and other food production systems (ESCWA, 2023). As a result, and as previously discussed, the outcome of such destruction is a catastrophic increase in hunger, food insecurity, and malnutrition in Gaza. Therefore, the achievement of the goal of ending hunger (especially target 2.1) will become more challenging in Gaza and the surrounding region. Lack of food has led to alarming levels of acute malnutrition and starvation (target 2.2), resulting in people falling dead of hunger, especially babies and children. According to the Palestinian Ministry of Health, at least 25 children have died from malnutrition and dehydration in northern Gaza by 12 March 2024. Even the medical crews in Gaza have suffered from malnutrition and had nothing to eat at the end of the first fasting day of Ramadan 2024 (Al-Jazeera, 2024).

The effects of wars on food security extend beyond immediate concerns, influencing long-term agricultural production and food supply chains (Deng et al., 2022; Kemmerling et al., 2022). When the current war on Gaza ends, environmental and economic damages will last for decades, leading to severe decrease in agricultural productivity and loss of income of small-scale food producers (target 2.3) (Buheji and Al-muhannadi, 2023; UNCTAD, 2024). Residence agriculture practices and sustainable methods were being adopted in Gaza, and starting to show success in 2020, with use of hydroponic, greenhouses, smart irrigation, and solar cells technologies (Muhie, 2022). However, the ongoing war has significantly damaged such sustainable food production projects and harmed all natural resources and ecosystems in Gaza, which will likely lead to reducing their resilience and adaptation to climate change and other natural or human caused disruptions (target 2.4).

In addition to their impacts on natural resources and ecosystems wars can lead to destruction of natural habitats for many species of

animals and plants as well as loss of biodiversity and genetic diversity (target 2.5) (Gallo-Cajiao et al., 2023; Shahini et al., 2024). Plant exposure to white phosphorus used in the current war and loss of farm animals due to bombardment underscore the significant toll that this war has taken on agricultural livelihoods as well as plant and animal genetic resources for food and agriculture in Gaza.

7 Potential global food security crisis due to the escalation and repercussions of the war

The effects of the war on Gaza have also started to create regional disruptions, and humanitarian aid diversion. The impacts on global food prices and trade can be significant. The international community's response has been strained. The efforts to address immediate needs and support long-term recovery of many areas around the region should be reinforced by effective mitigation measures (FAO, 2024c). ESCWA/UNDP (2023) mentioned that learning from past conflicts, there will be a potential regional spillover of the war on Gaza and on the progress towards SDGs in the region. Moreover, an earlier International Monetary Fund report warns that countries bordering high-intensity conflict zones in the Middle East and North Africa (MENA) usually experience a decline in average annual GDP growth by 1.9 percentage points (de Imus et al., 2017). This resulted in a constrained fiscal space, limiting the capacity to invest in sustainable development initiatives such that it may have a disproportionately negative impact on projects relevant to women development and vulnerable groups.

The disruptions in supply chains and fluctuations in global oil and gas prices might have an effect on Jordan and Egypt imports of gas. If the conflict results in shipping disruptions even oil imported from Saudi Arabia via tankers in the Red Sea could lead to an energy crisis. This might further aggravate the exchange rate leading to higher interest rates to combat inflation. ESCWA/UNDP (2023) warns that resultant inflationary trend would have implications for the broader economic stability of the MENA countries, and might lead to additional stress on both local and refugee populations who have already been facing an increased cost of living.

8 Mitigation measures and recommendations

Food security in Gaza is in a state of emergency as the result of catastrophic risks across the Strip and there is only a short window of time in which the international communities to act. With limited or no access to humanitarian assistance, a fast and rapid deterioration in the nutrition status of women, infants, and children under 5, resulting in wasting and risk of death is most likely, which necessitate an urgent response to save lives of people.

Food is one of the few things that people struggle to access as lack of food is threatening human life and survival. Hunger is becoming a key fact and threat to the people's lives in many parts of Gaza due to the ongoing war, blockade of borders, as well as mass destruction, which gives enough reasons that we should all be concerned and involved in tackling the growing food security and famine crisis. Looking at the size of the current crisis in Gaza, it is clear that

achieving durable solutions will require both short- and long-term approaches, with the ongoing war and unavailability of food to be placed at the centre of all decision-making at global forums and, most importantly, a commitment from the international communities and humanitarian agencies.

The first element when building successful solution strategies is to ensure the political will to secure the urgent food needs of the people, especially the most vulnerable groups through opening the borders and ensuring a wide-ranging food delivery that targets everyone in the strip. The food security crisis must not be only discussed among humanitarian agencies but rather the entire world must be involved. Children are the most vulnerable to the crisis and we need to feed each and every child to save lives, especially given the alarming and shocking reports and images showing children dying from malnutrition and dehydration over the last few weeks.

In order to achieve durable solutions to address the food insecurity and famine in the Gaza Strip, commitments from every stakeholder, including UNRWA, WFP, FAO, WHO, UNICEF and others are required to move towards a sustainable and equitable food, water, and health delivery and services, and build capability of the local government to feed and treat malnourished children and mothers. Although the UN system activated the Nutrition and Health Clusters to ensure the smooth delivery of essential food aid and medicines to the most vulnerable groups, still a stronger collaboration across humanitarian, development, peace, and security partners is critical for more and faster delivery in challenging environments, which is critical in the current response to address the food insecurity and famine in the Gaza strip. It is recommended to continue to support communities to help them reclaim their livelihoods, regain cohesion, and build resilience to future shocks. With protracted and recurrent crises as the new norm, the humanitarian agencies must do more to ensure the availability of the information, systems, and processes to help the Strip cope with the current crisis and to find innovative solutions via non-state actors, including the UN/NGOs agencies.

In the area of resource mobilisation and finance, we recommend developing mechanisms for financial protection for people in emergency settings, mobilising and coordinating resources to ensure flexible funding availability to cover priority urgent needs, and reviewing and adapting contingency funding specifically to prioritise essential food staff, nutrition, and medicine needs during the ongoing emergency situation. Ensuring a continuum of food supply and essential nutrition services through integrating food security and nutrition interventions into the national food and health sectors' response plans during emergencies is a priority. Additionally, it is important to maintain a continuous supply of essential food aid and medicines, including the severe acute malnutrition kit and necessary technologies for managing acute malnutrition at health facilities. Moreover, it is necessary to provide rapid training in food aid, food supply chain, and nutrition, focusing on vulnerable groups, including displaced and poor people in emergency settings. In the short term, it is crucial to foster cultural and local initiatives, such as *Tekias* (Palestinian community kitchens) that provide daily meals to families who are struggling to ensure enough food and water to stay alive.

The integration of food security and nutrition information systems and its indicators in emergency reporting systems is recommended for better targeting and assessment of impact of aid,

including initial rapid assessment, regularly map service needs, as well as food security and nutrition surveillance as part of the emergency dashboard for the humanitarian settings. It is crucial to activate social protection system and encourage income generating projects through promoting national projects gradually when the security situation is improved as part of the recovery plans focusing on national food production.

When the war in Gaza ends and during the recovery phase, it is recommended to diversify (i) markets (by reducing imports and multiplying trade partners), (ii) production (through sustainable intensification), (iii) crops (focusing on various food sources that provide macronutrients such as energy, protein, and fat), and (iv) technology (focusing on biotechnology and other new production technologies), in order to minimise the impact of the war, as recommended in other wars, such as the war in Ukraine (Neik et al., 2023). In the long term, developing resilient and sustainable food systems will be crucial to overcome food insecurity issues and other challenges in an integrated social-ecological way in the most vulnerable and fragile regions (Queiroz et al., 2021), such as the Gaza Strip.

9 Implications and limitations of this study

This study is the first to provide a general overview of the impact of this war on the six pillars of food security in Gaza and the various target of SDG 2. It serves as a springboard for future work and research to identify patterns of the ongoing war, showing its implications for constraining progress in achieving other SDGs. Results of this study show that the ongoing war on Gaza is normalising the weaponisation of food and basic necessities, undermining the achievement of SDG 2 and food security. The massive humanitarian crisis resulting from this war has significantly impacted food availability, accessibility, utilisation, and stability. The ongoing war on Gaza is causing immense suffering for 2.3 million people and a gloomy future for the 2030 Agenda. The already acute food insecurity in the besieged Strip is being now shifted into an unprecedented famine. Moreover, the study underscores the fact that potential escalation and repercussions of the war could lead to global food security crisis. Therefore, this research provides significant insights and information to political leaders around the world to build international partnerships and lead coordinated efforts to immediately stop the war and alleviate the humanitarian crisis in Gaza.

Given the early stage of research on the impact of the ongoing war on Gaza on food security and SDGs, the study has certain limitations, related to the used references and the expected outcomes, especially on the long term. Indeed, the study is partially based on short and fragmented reports and news coming from Gaza, which can impact the accuracy of results, potentially introducing biases or incomplete insights. Thus, the obtained results might not exactly represent the situation on the ground, highlighting the need for more detailed studies. Moreover, there is a certain degree of uncertainty, especially about the far-reaching consequences of this war since the outcomes will depend on both the evolution of this war and the response of the international community.

10 Conclusion

The 2023 war on Gaza has had profound and devastating effects on the besieged Strip, transforming it into a landscape of death and despair. Currently, there is no sign that the ongoing war will end soon, meaning that aspects related to food availability, access, utilisation, and stability will be further affected in the coming weeks and months.

The war's impact on food security, specifically in relation to SDG 2, is of utmost concern. The relentless bombardment and ground incursions in Gaza have led to devastating consequences for food security, exacerbating the already existing acute insecurity caused by years of blockade and previous military attacks. One of the most significant consequences of the war has been the widespread destruction of essential food facilities, including bakeries and food factories. These facilities play a crucial role in producing and distributing food items that are essential for daily sustenance. The massive use of weapons and missiles has destroyed food production facilities and farmland, leaving many families with no choice but to resort to desperate measures, such as consuming animal feed and weeds, to stave off hunger. Targeting such infrastructure has disrupted the food supply chain, resulting in food shortages and price increases for basic food items. For example, access to bread, a staple food, has become increasingly limited, further worsening food insecurity. More alarmingly, evidence shows heinous repetitive attacks of civilians while waiting for flour and food distribution, especially in northern Gaza, which have triggered worldwide condemnations.

The destruction of agricultural land and food facilities also has long-term implications for food security. The loss of productive farmland not only threatens the immediate food supply but also hinders the region's ability to recover and rebuild its food system after the war. The reconstruction of agricultural infrastructure and revitalization of food production systems will require significant investment and resources, further straining humanitarian efforts in the region. As civilian starvation is weaponized in this conflict, Gaza faces the grim reality of becoming the world's worst hunger crisis, with the specter of famine looming over its population. The deliberate targeting of Gaza's food system not only violates fundamental human rights but also undermines global efforts to achieve zero hunger by 2030. This unprecedented assault on Palestinians not only threatens the lives and livelihoods of those directly affected but also has far-reaching implications for the environment and global food security.

The international community's response to the Gaza crisis is of utmost importance and involves several key actions. Firstly, urgent humanitarian assistance, including vital supplies such as food, medical aid, and shelter, must be swiftly delivered to alleviate the suffering of the innocent civilians in Gaza. Additionally, influential states and regional bodies must engage in diplomatic efforts aimed at resolving conflicts and addressing the root causes of the crisis. This will ensure the protection of civilians and guarantee their access to food as a fundamental human right. Furthermore, world leaders must exert political pressure on the conflicting parties to adhere to humanitarian law, prioritize the protection of civilians, and facilitate access to aid to those in need. This encompasses condemning attacks on civilian infrastructure and advocating for the lifting of restrictions that exacerbate the dire situation in Gaza.

In addition to immediate assistance, long-term development support is essential. Investment in rebuilding infrastructure, boosting

the economy, and improving living conditions is crucial for the people of Gaza. This involves supporting reconstruction efforts, promoting education and healthcare, and facilitating economic development in this war-torn region. Lastly, the promotion of human rights, which includes ensuring food security for all, is indispensable. States must prioritize the safeguarding of the rights of Gazan civilians and hold those responsible for violations accountable. Failure to effectively address the Gaza crisis not only further deepens the suffering of the people of Gaza but also undermines the broader goals of sustainable development and global food security. Therefore, the international community must come together and take decisive action to alleviate the crisis and pave the way for a better future for the people of Gaza.

Author contributions

AbH: Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. KA-M: Data curation, Writing – original draft. HH: Writing – original draft. AhH: Writing – original draft, Visualization. KK: Writing – original draft. MB: Supervision, Writing – original draft. AJ: Funding acquisition, Writing – original draft.

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Food system under COVID-19 lockdown in Shanghai: problems and countermeasures

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Introduction: Owing to the increased transmissibility of the Omicron virus, Shanghai implemented a citywide lockdown in 2022. This measure disrupted the normal functioning of the city's food system and led to incidents related to food insecurity within the city. To mitigate these challenges, the local government and various stakeholders devised various solutions.

Methods: In this context, we adopted a root cause analysis to report the disruptions caused by the lockdown on Shanghai's food system.

Results: According to disruptions, we listed the challenges faced by Shanghai's food system and solutions implemented by the government and stakeholders.

Discussion: We discussed the underlying reasons behind food system disruptions and listed advantages of Shanghai's solutions. We further scrutinized the sustainability of the solutions implemented in Shanghai. Finally, we discussed how to promote the urban food system resilience building based on research findings. The findings of this research are anticipated to provide valuable insights for other areas that may encounter similar challenges in the future while fortify their urban food systems.

KEYWORDS

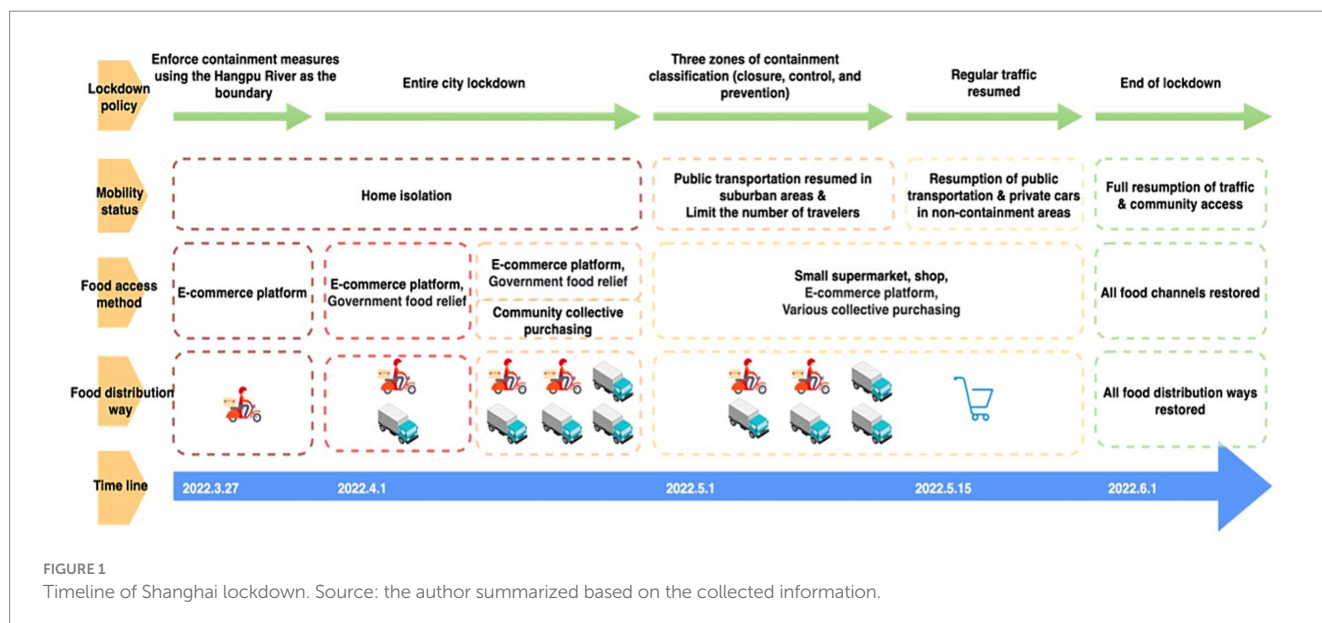
COVID-19 pandemic, lockdown, food system, food security, urban

1 Introduction

Since 2020, the novel coronavirus rapidly spread globally. Countries, sub-national regions, and cities worldwide responded to the COVID-19 pandemic through prevention and control measures. However, these measures significantly disrupted the infrastructure and systems upon which cities depend, in particular, impacting the food system functioning, and subsequently affecting food security.

The COVID-19 pandemic prevention and control measures profoundly influenced local food systems (Béné, 2020; Béné et al., 2021), especially the urban food systems (CCSA, 2020). Given that over 90% of new COVID-19 cases occurred in urban areas because of the high population density, risk of infection during routine food supply and purchasing activities increased (COLL, 2020). Therefore, prevention and control measures were more frequently enforced in urban areas than rural regions.

Shanghai, China's largest city, was severely affected by lockdown measures that obstructed its entire food system. Since early March 2022, as the number of infections increased, the scope of control strategies in Shanghai gradually expanded. Notably, from March 27th to June 1st, 2022, Shanghai implemented stringent measures to block the entire city with 2,500 residents (Figure 1) (Shanghai Statistics Bureau, 2022). The lockdown measures were continually adjusted according to the severity of virus transmission, indicating dynamic food system adjustment. During the earlier stages of the Shanghai lockdown, rapid lockdown initiation



caused food system disruptions. Food supply and food distribution was insufficient because of road closures and quarantine inspections limiting the flow of food logistics. Most food retail and catering entities were forced to close, severely restricting resident access to food channels, while the residents' scope of activities was also greatly reduced, further exacerbating their channels of obtaining food. In response, from April 1, the food system was adjusted to address the food needs of the majority of the population during the mid-term of the lockdown. As the virus spread was under control (On April 20, Jinshan and Chongming Districts in Shanghai reached zero infections on a societal level; by April 30, the entire city reported zero infections on a societal level). Lockdown measures began to moderate, and food system channels cautiously expanded. Until June 1st, when the virus was effectively controlled, all food system channels were restored. The urban food system stagnated from the supply side to the demand side, resulting in food insecurity issues at the household level. Furthermore, the rapid initiation of the lockdown in Shanghai resulted in a significant increase in depression and anxiety due to household food insecurity (Hall et al., 2023). Therefore, it is crucial for the government to ensure city-wide food supply to prevent food security issues resulting from shortages in food supply and insufficient access channels.

2 Literature review

Local food systems in various countries faced the same challenges during the pandemic. Complex urban food systems revealed the vulnerabilities and structural weaknesses. The unsustainability, inequity diminished the urban resilience to maintain food and nutritional status (Jensen and Orfila, 2021). Numerous issues surfaced during the pandemic, such as the disarray in coordinating responses across multiple departments, inflexibility in local food supply system policies, and the cascading effects resulting from the pressure on social and public sector services, all of which led to inadequacies in the operation of urban food systems (Hecht et al., 2019; Newell et al., 2022). Weaknesses in the areas of labor, processing, transport and logistics were highlighted (Béné, 2020). The unequal impact of food

security and services exacerbated conflicts among populations (Cattivelli, 2022). The relationship between metropolitan areas and nearby rural areas was characterized by a number of issues that need to be addressed, such as the role of peri-urban agricultural zones in ensuring food supply and land conservation, and the need to develop cooperation and mutual assistance activities among the different agents involved in the food system (Callau-Berenguer et al., 2022; Cattivelli, 2022). Although these issues reflect barriers to the transformation of urban food systems, they also represent opportunities for reform.

The COVID-19 pandemic exposed weaknesses in our emergency food distribution plans, emphasizing the importance of actively fostering adaptability in such plans. The adaptability was reflected in the actions of stakeholders at all levels. The vulnerability of the food system resulting from a high reliance on long-distance transport and cold-chain logistics was recognized, and the alternative was a more decentralized and localized short food supply chains (SFSCs) (Chi Ffoleau and Dourian, 2020; Shariatmadary et al., 2023). In government management, studies demonstrated the coordination of governmental activities alongside strategic alignment of policy initiatives. Examples include the government's management of partnerships and coordination among the public, private, and third sectors, as well as policies and initiatives implemented at the local level (Kroll and Adelle, 2022; Parsons and Barling, 2022; Turcu and Rotolo, 2022). However, due to the fast-paced and highly uncertainty of pandemics, this required a rapid response from all actors. This further exposed the existence of a disconnection between the national level and the city level of urban food governance, and fragmentation at the level of urban management (Turcu and Rotolo, 2022). Therefore, in situations where mainstream actors and institutions in the food system were slow or inadequate in their actions, local grassroots initiatives played a crucial role in ensuring food access, supply, and distribution. During the pandemic, local grass-roots actions addressed food security primarily through a people-centered approach, supplemented by third sector and community-led initiatives, revealing a new structure of food governance in the city (Turcu and Rotolo, 2022). These measures were considered innovative during the pandemic, as they are flexible and based on local characteristics, and are considered effective in

enhancing the resilience of local food systems. For example, non-governmental organizations, community groups, and residents' associations utilized existing resources to establish networks with both public and private organizations (Mockshell and Nielsen Ritter, 2024; Rut and Davies, 2024). They also coordinated with other regional food distribution centers to facilitate food sharing, mutual aid, and assistance activities, maximizing their impact in bridging the gaps in the local food distribution chain (Lofton et al., 2022; Mockshell and Nielsen Ritter, 2024). In addition, the flexible utilization and adaptive transformation of existing facilities and strategies alleviated pressure on the urban food system. For example, repurposing existing infrastructure (such as converting grocery stores into emergency food warehouses). Urban agriculture, community gardens, household gardens, and roadside vendors played important roles in providing food emergency buffer functions (Lal, 2020; Iida et al., 2023; Underhill et al., 2023). It is worth noting that e-commerce platforms, ensuring smooth information flow and contactless communication features, have also been proven effective in reducing the risk of infection and meeting urban food demand (Guo et al., 2021; Wang et al., 2022).

China, the world's most populous country, particularly experiences denser populations in its large cities, with more complex and diverse food systems. Faced with the rapid spread of the pandemic, the challenges confronting the food system are more formidable compared to other regions. Urban systems also implemented various measures to address this challenge. Existing research explored the overall urban governance and resilience measures of urban systems in China during pandemics (Xue et al., 2023). Research also addressed the exploration of methods and frameworks for future urban emergency response based on existing development concepts and policies in cities (Blay-Palmer et al., 2021; Fei et al., 2023). Additionally, study summarized food security governance in some cities and reviewed emergency food policies and their impact on urban household food security (Zhong et al., 2022; Chang et al., 2023).

In summary, from our understanding of existing literature, the research addressed the challenges faced by local food systems during pandemics on one hand, while also evaluated the measures taken by local food systems to respond to these challenges on the other hand. However, there is a lack of dynamic discussion regarding the challenges and solutions encountered by a city during a pandemic. Because the fast pace and high degree of uncertainty during a pandemic make it difficult to track and assess changes in the food system and related policy responses (Ilieva et al., 2023). Additionally, current research exhibited a deficiency in systematically coordinating stakeholder response cases across all levels. Given the rapid implementation of strict regulations, it becomes imperative to explain how the Shanghai government effectively coordinates the collaboration of diverse stakeholders to promptly sustain the functionality of the food system within a mega-city housing 25 million residents. This demonstration is essential for sharing useful practices to the global urban area. Therefore, we propose the first research objective RO1: based on the dynamics of the pandemic in Shanghai, we demonstrate the challenges that emerged at various stages of the city's food system. The study also identifies the systemic and structural deficiencies exposed by the city in light of these challenges and suggests improvements. However, collective behavior also exhibited confusion and discourse distortion at different stages of the pandemic (Xue et al., 2023), some response measures only focused on short-term crisis management and maintaining the status (López Cifuentes and Fiala, 2022). In response to these shortcomings, we propose the second

research objective RO2: enumerate the response measures taken by governments and stakeholders in various stages of the pandemic in light of the main challenges and evaluate the sustainability of these measures. The increase in resilience is most effective when multiple institutions, organizations, and individual citizens collaborate under a common strategy toward shared goals (Borrelli et al., 2023). The key aspect of this process is the development of a more comprehensive approach. Therefore, we propose the third research objective RO3: based on the listed challenges and response measures, combined with current technology and science, discuss how to build a more resilient urban food system to cope with future uncertainties.

Based on the outlined research objectives, our study holds significant implications: firstly, by identifying and analyzing the challenges that emerged in Shanghai's food system during the pandemic, our research provides valuable insights into the vulnerabilities and deficiencies of urban food systems in the face of crises. This understanding is crucial for policymakers, urban planners, and stakeholders to develop effective strategies and policies to enhance the resilience of food systems in similar contexts. Secondly, through an evaluation of the response measures implemented by governments and stakeholders in response to pandemic challenges, our study offers a critical assessment of the effectiveness and sustainability of these measures. This evaluation could inform future crisis management strategies and guide decision-making processes to ensure more adaptive and resilient responses in the future. Lastly, by discussing how to build a more resilient urban food system based on identified challenges, response measures, and current technology and science, our research contributes to the development of practical solutions for mitigating future uncertainties. This discussion provides actionable recommendations for enhancing the resilience of urban food systems, ultimately contributing to the long-term sustainability of cities in the face of global challenges. In summary, our study provides valuable insights, evaluations, and recommendations for policymakers, practitioners, and researchers to enhance the resilience of urban food systems and effectively manage future crises.

3 Methods

3.1 Data source

We conducted data collection according to the logic depicted in Figure 2. Owing to the scattered and transient characteristics of the event, we gathered information from diverse sources to describe the situation. To ensure accuracy, we compared information from both official and unofficial sources. The information utilized for analyses from publications, government-released reports, official information as well as blogs and media articles. The study was compliance with standard reporting guidelines. Ethics approval was deemed unnecessary for this study, as the research protocol did not involve any interventions or compromise privacy and anonymity. All data utilized in this study underwent thorough de-identification measures.

3.2 Analysis method

This study employed a qualitative analytical approach to describe and analyze disruptions and challenges to the urban food system in

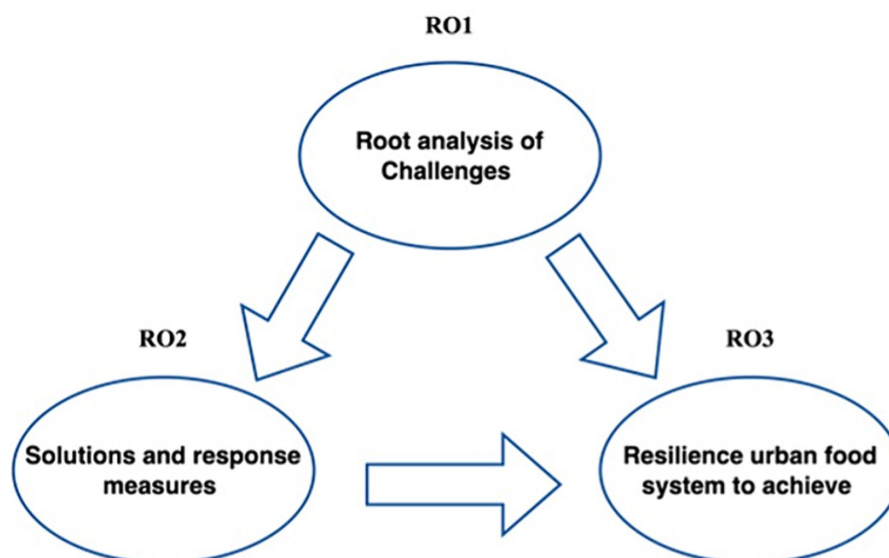


FIGURE 2
The research framework- RO1, RO2, and RO3.

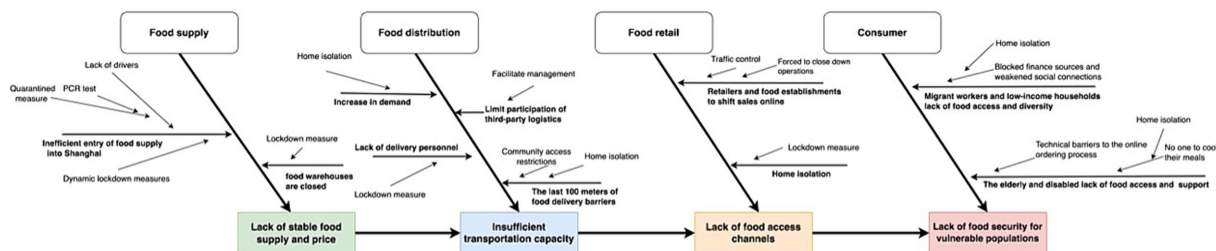


FIGURE 3
Root cause analysis of challenges. Source: the author summarized based on the collected information.

Shanghai during the COVID-19 lockdown from the March 27 to the June 1, 2022, along with corresponding mitigation solutions. Root cause analysis (RCA) is a systematic method of identifying the underlying causes of problems or incidents, rather than simply addressing their immediate symptoms. Using this method, we identified the reasons for the challenges in the Shanghai food system (Figure 3), why these challenges occurred. Based on root cause analysis result, we also summarized that how Shanghai responded to these challenges, how sustainable are these measures for the urban resilience food system building, and what we should do to avoid the recurrence of these challenges.

4 Results

4.1 Impact of lockdown on Shanghai's food system and challenge

4.1.1 Overview impact of lockdown on Shanghai

The impact of *food production* in Shanghai's food supply chain faced minimal disruption. To address the short-term urgent needs,

perishable foods such as milk and leafy greens experienced minimal impacts because of support from the surrounding regions. In 2022, Shanghai's surrounding areas dedicated a total of 803,200 mu to grain production, 490,700 mu to vegetable production protection zones, and 71,000 mu to specialty agricultural product advantage zones (Gu, 2022). Overall grain production remained stable at over 900,000 tons, with perennial vegetable acreage consistently at around 500,000 mu (Gu, 2022). Approximately 80% of the city's leafy greens could be supplied by these surrounding areas (Gu and Wang, 2020). In addition, the collaboration between the government and major corporations provided essential food support. Guangming, a state-owned food company in Shanghai, demonstrated a dominant market presence in 2022, particularly in the dairy and meat sectors. The company's market share exceeded 80, and 40% in dairy products and meat, respectively (Zhong, 2022). Moreover, the government collaborated with these companies to enhance food security by utilizing their storage facilities for grain reserves. For example: Guangming had an annual grain reserve throughput exceeding 10 million tons (Zhong, 2022). This company is also a significant player in Shanghai's wholesale agricultural market, holding 60% market share in packaged rice and accounting for 70, 60, and 50% of the city's

total wholesale volume of vegetables, meats, and fruits, respectively (Zhong, 2022). These solutions played a pivotal role in diminishing short-term overall emergency food supply pressures in Shanghai.

In the long term, to compensate for local supply shortages, areas outside Shanghai provided essential support. Because 85% of the grains, 75% of the vegetables and meats, and 65% of the eggs and dairy products in the entire city rely on supplies from other provinces and cities (Shanghai Municipal People's Government, 2022a,b). According to the State Council regulations, agricultural production could be resumed in low-risk areas (The State Council of the People's Republic of China, 2020). These areas were identified based on the COVID-19 pandemic and demographic data, where people were less likely to infect each other (Cheng et al., 2021). The Shanghai Municipal Commission of Commerce, in collaboration with wholesale markets, developed emergency plans. These plans involved reserving vegetables in low-risk areas such as Jiangsu and Shandong provinces to address shortages (Shanghai Municipal Commission of Commerce, 2022a). To ensure smooth supply, green channels for inter-provincial food transportation ensure the efficient delivery of food to Shanghai (The State Council of the People's Republic of China, 2022). These policies guaranteed food production continuity in agricultural areas and food logistics efficacy between provinces. Thus, provinces and cities located in low-risk areas could provide substantial food aid supplies and fulfill food demand orders for Shanghai. Similarly, *food processing and packaging* faced minimal disruption. As most food-processing factories are located in areas with low resident densities, they were less likely to become high-risk areas for viral transmission, thereby protecting continuous production activities.

Although there was an ample food supply available to Shanghai, stringent traffic control and pandemic prevention checks in Shanghai hindered the transportation of food into the city, resulting in ineffective distribution and lack of food access channels. Therefore, the most significant impact on Shanghai's food supply chain stemmed from interruptions in the *food distribution and retail channels* (Figure 3). The main challenges as follows.

4.1.2 Challenge 1: lack of stable food supply and price

Although the overall food supply was adequate, inner city food supply faced the uncertainty regarding viral transmission led to frequent changes in lockdown measures. As most food items were transported by road using trucks owned by manufacturers, distributors, or third-party transportation companies, external personnel and vehicles faced challenges when entering Shanghai City (Figure 3). They were required to obtain permits and PCR test report before being allowed to proceed. This reduced the efficiency of food supplies entering the city. Once an incident of infection was detected in the transportation staff, they were quarantined for 14 days. This caused some drivers to fear quarantine and refuse to transport goods to Shanghai, resulting in driver shortage. At the beginning of April 2022, the number of vehicles transporting fresh agricultural products into Shanghai plummeted from 3,000 per day to 600 (Shanghai Municipal People's Government, 2022a). Besides, dynamic lockdown measures interrupted planned transportation routes at any time. After food supply entered the city, most food warehouses were closed due to pandemic prevention policies, resulting in a short-term shortage of food reserves within the urban area. Correspondingly, the imbalance between decreased food supply and increased demand led to

significant price increases during this period. Some businesses also engaged in illegal price gouging practices (Shanghai Municipal Administration for Market Regulation, 2022).

4.1.3 Challenge 2: insufficient transportation capacity

As the number of infections rose sharply, the movement of couriers had a high potential for cross-infection. To facilitate management, the government limited participation of third-party logistics, permitting a limited number of transportation companies to operate within Shanghai. During normal periods, third-party logistics companies handled 70% of the logistics tasks in Shanghai. However, with the restrictions imposed on the involvement of third-party logistics, it is equivalent to a reduction in an equal amount of logistics transportation capacity. In 2022, the volume of local express delivery services reached 600 million parcels, representing a year-on-year decrease of 27.5% (Shanghai Statistics Bureau, 2023). Given the remaining transportation companies focused on essential government operations and the transportation of critical supplies, the logistics capabilities were further constrained. To meet the urgent food needs of residents, couriers who passed pandemic prevention checks were being issued city permits. Their numbers still could not meet the needs of the entire city. They were tasked with delivering food ordered by residents through e-commerce platforms to residential communities. However, due to the limitations of the lockdown policy, couriers were not allowed to enter the community and residents were not allowed to go out of the community, which made the last 100 m of food delivery become challenging (Figure 3).

4.1.4 Challenge 3: lack of food access channels

Mobility restrictions forced retailers and food establishments to shift sales online, making online grocery the sole grocery channel in Shanghai. The residents were also restricted from going out. Those led to a lack of food access channels, resulting in insufficient food diversity, limited proximity, and inconvenient food access environments. Moreover, due to the shortage of delivery personnel, the high transportation costs and insufficient distribution effectiveness also hindered households from relying on the only way (online grocery) to obtain food (Figure 3).

4.1.5 Challenge 4: lack of food security for vulnerable populations

Vulnerable populations in Shanghai also encountered challenges in food distribution. Due to lacking food access channels, people were starting to seek informal channels to obtain food, relying on personal connections or social networks. Migrant workers and low-income households earned income through part-time jobs, small businesses, and labor-intensive industries, had lower social resources and well-being than normal residents. This placed them at a disadvantage in securing food resources. Besides, due to lockdown mobility limitations, blocked finance sources and weakened social connections, further diminishing their food diversity. The food security of the elderly population is also a challenge. Among Shanghai's 14 0.7 million registered residents, there are 5.33 million people aged 60 or above, accounting for 36.1% of the population (Shanghai Hongkou District Government, 2023). Especially those without family or social support faced technical barriers to the online ordering process or no one to cook their meals. There were also more than 20,000 registered families

with serious illnesses in Shanghai (Wang et al., 2022). They required specialized support in their daily lives, and obtaining essential medicines and food could become even more challenging during the lockdown period (Figure 3).

4.2 Solutions and countermeasure of food supply in Shanghai

4.2.1 Overview of Shanghai's solutions

An overview of the emergency food supply system in Shanghai during the pandemic is shown in Figure 4. It was established by the government, in collaboration with several stakeholders. To face the challenges during the early stages of lockdown, this system addressed the issue of unstable food supply inside the city, mitigated logistical pressures, and established a robust and equitable food access channel to meet the overall food supply needs (Figure 5). The system primarily relied on guaranteed supply companies cooperating with collective purchasing as the primary supply channel, supplemented by government food relief and individual online grocery. Third-party logistics companies were responsible for filling up transportation gaps, while local communities and volunteers were responsible for the final food delivery. The emergency food supply system process included the following steps: (1) Demand collection: resident demands were

collected from three main sources (Figures 4B,C). Firstly, the district government collected residents' basic information through community committees to meet their basic food needs. Secondly, collective purchasing organizers regularly collected information about the types and quantities of food demanded by each household in the community, and then transmitted this information to guaranteed supply companies for centralized delivery. Thirdly, residents placed orders through e-commerce applications to satisfy specific requirements. (2) Food distribution: government food relief and collective purchasing were primarily handled by guaranteed supply companies for city centralized delivery with third-party logistics companies assisting in reducing transportation pressures. Online individual orders were delivered by individual delivery drivers (Figures 4B,C). (3) Last 100 meters of food delivery: after the community committee received the collective food supply, volunteers delivered food packages to the residents (Figure 4C).

4.2.2 Solutions to challenge 1

To ensure the smooth supply of food into the urban areas, Shanghai established food transfer stations on the outskirts of the city (Figure 4A). These stations facilitated the transfer of goods without direct contact, thereby minimizing the risk of infection for drivers from other regions (Shanghai Municipal People's Government, 2022a,b). This setup also ensured that external drivers, as indicated by

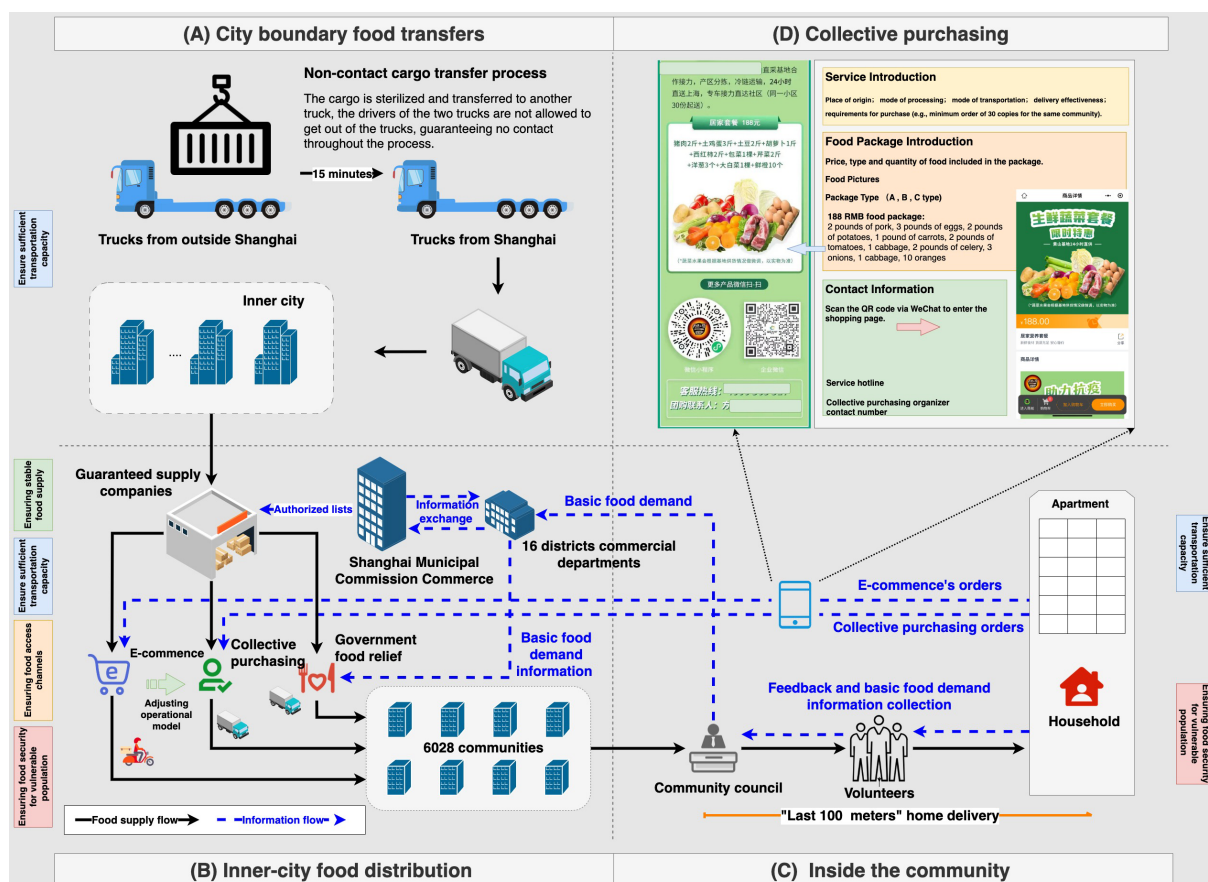
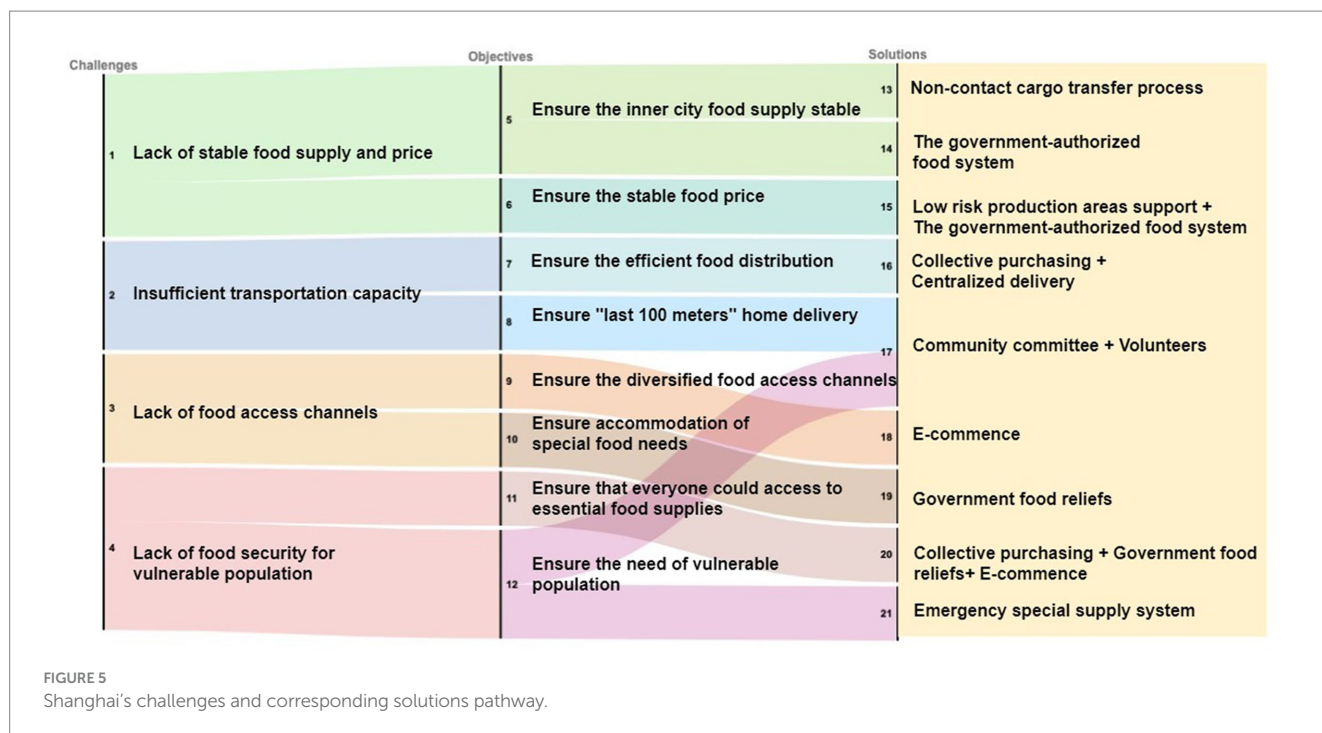


FIGURE 4
Shanghai's emergency food system's explanation.



the comprehensive data system, were not entered high-risk areas, alleviating concerns about potential infection and quarantine.

To ensure smooth food distribution within the urban areas, a government-authorized food system was established, ensuring food supply remains unaffected by lockdown policies. Entities participating in the food supply received Shanghai Municipal Commission Commerce's authorization. This protected them from interference by the lockdown control measures. These companies on the Shanghai Ministry of Commerce's authorized list were also announced to the Shanghai district governments to facilitate the establishment of cooperation between the district governments and these companies. This enhanced the efficiency of food distribution at the district level. In addition, Shanghai's Jing'an and Qingpu districts took the initiative to establish cooperation with agricultural cooperatives and places of origin to simplify the channels of urban food supply (Shanghai Municipal Commission of Commerce, 2022a). With food supply stabilizing, the overall market prices in Shanghai were also stabilizing. However, there were still some businesses engaging in price gouging. To address this issue, the Shanghai Market Supervision Administration stipulated profit margin regulations during the pandemic, specifying that the profit margin rate during the pandemic should not exceed the highest rate within the 7 days preceding March 19, 2022 (General Office of Shanghai Municipal People's Government, 2022).

4.2.3 Solutions to challenge 2

To address insufficient transportation capacity, a collaborative model was implemented in which guaranteed supply companies cooperated through collective purchasing to effectively mitigate logistical pressures (Figure 4B). Each household reported the type and quantity of food needed for a certain period to the collective purchasing organizers through a WeChat application or phone calls (Figure 4D). Organizers collected this information and submitted collective orders to guaranteed supply enterprises. According to order

demands, guaranteed supply enterprises arranged for collective food demand delivery. Fewer trucks that made a single delivery were sufficient to meet the food demands of an entire community for a specific duration. For example: Pudong New Area with its population of 6.5 million residents, 2.6 million households, if each household receives a 5-kg food package, it only requires over 600 trucks (Shanghai Municipal People's Government, 2022a,b). This model ensured that despite the number of drivers and logistics staff was limited, it was possible to guarantee a large quantity of food and met the personalized food needs of each family. In addition, to address the logistical shortage caused by a further surge in food delivery demand, some third-party logistics were granted the permission to collaborated with guaranteed supply companies for food delivery as well (Shanghai Municipal Commission of Commerce, 2022b). To complete the last 100 meters of food delivery, the community committee organized resident volunteers to collaborate on the task. These volunteers were responsible for receiving food supplies (including collective purchasing, government food relief, and online grocery). After external packaging and disinfection, the community volunteers arranged food distribution tasks based on order information, volunteers delivered food packages to the residents' doorsteps, where they could pick them up, thereby ensuring a contactless food delivery process. The community-driven approach ensured efficient and safe delivery of essential food items to households (Figure 4C).

4.2.4 Solutions to challenge 3

To increase the number of purchasing channels that are multiple and meet the food needs of most of the population, Shanghai established three food access channels in its food supply system (Figures 4B,C). (1) The food reliefs were funded by the government and designed to ensure that all residents could access the most basic food needs. The government obtained demographic information from every community and distributed free food packages including fresh

vegetables and meat products. (2) Collective purchasing ensured that the majority of the population had a stable and personalized food access channel. (3) Compared to the early stages of the lockdown, the role of online grocery undergone a fundamental shift, transitioning from a primary acquisition channel to a supplementary one. Individual online orders via a supplementary channel covered the special needs of a small group with items not available through the first two channels.

4.2.5 Solutions to challenge 4

To address the lack of food security for vulnerable populations, Shanghai adopted food reliefs to guarantee basic food needs for all residents. Also, the mechanism of collective purchasing in combination with guaranteed supply enterprises greatly improved the efficiency of food distribution and provided a stable food supply for all residents. Particularly, for the needs of the elderly, pregnant women, infants and young children, and people with disabilities, the Shanghai Municipal Commission of Commerce established an emergency special supply system with guaranteed supply companies (e-commerce platforms and large supermarkets) (The Shanghai Municipal Health Commission, 2022). Companies provided special purchasing channels for these individuals. Residents only need to input their personal information and medical history into the system, and staff contacted with them to provide food and medication. To ensure the effectiveness of these emergency needs, supplies were transported by dedicated vehicles. For those who faced difficulty using the internet, the community committee posted information about food resources on community bulletin boards or made household interviews so that people with no internet technical proficiency could inform the community committee of their food needs.

4.2.6 The practical effects of the Shanghai solution on the food system

In the initial stages of the lockdown in mid-March, the supply system provided Shanghai with a daily average of 10,204 tons of vegetables and 1,305 tons of pork (Shanghai Municipal People's Government, 2022a,b). As the number of supply guarantee enterprises continued to increase, by May 1st, the number had grown from the initial 4 to 1,400, ensuring an increase in both the quantity and variety of food. From May 1st to the 19th, a total of 390,000 portions of meat meals and 410,000 vegetable meals were supplied through the supply guarantee system (Shanghai Municipal People's Government, 2022a,b). To ensure the smooth operation of food logistics, 10 third-party cold chain logistics companies were incorporated into the supply system (Shanghai Municipal Commission of Commerce, 2022b). From the early stages of the pandemic to May 15th, the government provided free food channels, distributing a total of 7.658 million sets of living supplies to elderly people (Shanghai Municipal People's Government, 2022b).

5 Discussion

5.1 Reflection on the challenges within the food system

The 2-month lockdown in Shanghai posed four main challenges to the food system, prompting a reflection on the underlying reasons for these issues. Due to the coherence of the food system, these challenges collectively indicate a lack of a well-developed food emergency mechanism to address crises. The formulation of lockdown policies

hindered the operation of the food system, highlighting a disconnect between the functioning of the food system and the formulation of emergency policies. Therefore, a systemic approach to understanding the complexity of actors, activities, driving factors, and their interrelationships is crucial (Moragues-Faus and Battersby, 2021). This helps to clearly illustrate how urban food system planning and policies should consistently consider the entire food supply chain, highlighting disparities and disconnects to guide effective action on the ground (Clark et al., 2021; Moragues-Faus and Battersby, 2021). It is worth noting that this systemic thinking becomes even more crucial for urban governance during emergencies to avoid food system breakdowns caused by haphazard emergency planning. For instance, research proposes the design of Emergency Regional Food Supply Chains (ERFSC) under government intervention. The model considers regional food chain dynamics and labor demand forecasts under government intervention. This aids in alleviating efficiency losses in the food supply chain due to restricted labor during lockdowns (Tian and Mei, 2023). Therefore, expertise and foresight are essential. This necessitates greater involvement of scholars or professionals in urban policy formulation to avoid the disconnect between policies and actions within the food system.

Although food supply in Shanghai was generally adequate during this lockdown, thanks to the continued modernization of China's food warehousing facilities, there was a significant increase in logistics capacity and functioning road facilities. However, the inefficiency of food supply across city borders leads to instability in internal supply within the city. This reveals structural deficiencies in Shanghai's urban food system, characterized by excessive reliance on external food supply. Therefore, it is necessary to break down the spatial isolation of the city (Havewala, 2021) and ensure smooth food supply channels. The City Region Food Systems (CRFS) emphasizes the connectivity between urban areas and their surrounding regions, including rural areas. It proposes that urban-rural partnerships and intercity cooperation should transcend traditional administrative boundaries, reflecting an integrated food system between cities and their surrounding areas (Food and Agriculture Organization of the United Nations, 2024). Similar to the CRFS concept, Short Food Supply Chains (SFSC) and Local and Regional Food Systems (LRFS) are considered to have stronger resilience compared to long-distance transportation during pandemics. This is because they are closer to urban areas and less susceptible to disruptions, thus effectively supporting urban food security during the pandemic (Thilmany et al., 2021; Vicente-Vicente et al., 2021; Maas et al., 2022). Therefore, a more decentralized and localized food system needs to be established. Urban agriculture offers the potential for localized food systems. Vegetable gardens, home gardening, community gardens, and vertical farming have been proven to effectively enhance the food resilience within cities, reducing the vulnerability to sudden disruptions in food supply (Lal, 2020; Phooi et al., 2022; Elton and Cole, 2024). The social and public benefits of urban agriculture, including its potential to provide nutritional sustenance in post-disaster situations and serving as a contingent food source, should not be ignored (Sioen et al., 2017).

5.2 Advantages and sustainability of Shanghai solutions

5.2.1 Advantage of Shanghai's solutions

To address the four challenges faced by the food system, Shanghai has implemented a series of measures: our study highlights the

following three advantages of Shanghai's measures that ensure the efficiency and applicability of its food system.

5.2.1.1 Systemic coherence and efficiency

Shanghai's solutions avoided confusion, duplication of efforts, mismanagement, and general inefficiency by establishing a government-led emergency food system. Firstly, the use of big data facilitated productive activities to be conducted in low-risk areas, enabling Shanghai to obtain food from other regions, and guaranteed overall food availability. Secondly, because the appointed guaranteed suppliers were directly available to the government, inefficiencies related to outsourced suppliers are avoided. The cooperation model between the collective purchasing and guaranteed supply companies improves logistics efficiency and overcomes challenges arising from insufficient logistics staff. Collective purchases and guaranteed supply companies based on e-commerce platforms also ensured the traceability and visibility of the food supply. Furthermore, implementing transportation policies and establishing joint supply emergency systems in major production and consumption areas have been proven to play a significant positive role in stabilizing food prices (Cui et al., 2023). Lastly, the collaborative efforts between communities and volunteers ensure minimal contact and efficient food delivery.

5.2.1.2 Smooth information exchange channels

The communication channels established by the community councils between the residents and the district governments have been effective in ensuring the availability of food to all residents and mitigating food concerns. On one hand, the community reported basic information about the demographic situation and livelihood demands to the district government, thus ensuring efficient distribution of government's food reliefs and collective supply. On the other hand, the latest policy measures and food supply information were disseminated to the residents through the community committees. This ensured that residents remained informed about the policy implementation and reduced their food shortage concerns which could be effective in reducing psychological panic among residents (Zhang et al., 2022). Besides, community committees routinely collected feedback from residents regarding issues related to food quality and quantity to district government.

5.2.1.3 Accurate meeting everyone's food needs

Collective purchasing provides Shanghai residents with diverse food supplies, ensuring that everyone can access food according to their needs. To complement collective purchasing, individual online shopping also offers additional choices for specific needs. Specifically, for vulnerable households (elderly, disabled individuals, pregnant women, and infants), the government collaborates with supply guarantee enterprises to establish a special supply system, accurately collecting information on vulnerable populations. The community committees also regularly collected their demands, and then the special group emergency supply delivery channel promptly provided them with assistance.

5.2.2 Sustainability of Shanghai's solutions

The emergency governance and actions toward resilient urban food systems need to maintain sustainability to address the growing natural and man-made disasters caused by climate change. In the solutions proposed in Shanghai, we believe that certain actions, such

as collective action, community governance, and innovative food business models, enhance the resilience of the city's food system and are sustainable. These measures are based on the local policy environment, social structure, and lifestyle habits. For instance, the strong policy coherence between the central government and local governments enhances the responsiveness of implementing collective action. While the effectiveness of these measures remains to be verified in other social contexts, collective purchasing behavior has been proven in Rome to contribute to the resilience of metropolitan food systems during lockdowns (Tarra et al., 2021). Additionally, collective purchasing or online shopping for fresh food are based on existing shopping habits of residents, which are likely to continue post-pandemic. These behaviors not only serve as crucial channels for food emergencies but also remain a primary way for residents to access affordable food sources in their daily lives.

While these solutions have established a more equitable and efficient urban food system during the lockdown, many actions appear to focus on short-term crisis management and maintaining the status quo. This hinders the sustainable transformation of urban food systems toward greater resilience. Firstly, government intervention is perceived as conflicting with market forces. Government-led system has limited market participation, resulting in market monopolization by guaranteed supply companies. This has led these companies to suppress other food supply channels to maximize their profits. For example, food assistance from other areas conflicted with the interests of guaranteed supply companies, resulting in delayed distribution and food spoilage. Furthermore, due to the fact that supply guarantee enterprises are simultaneously responsible for government food relief and centralized supply distribution, some of these enterprises, in order to maximize their profits, may provide low-quality food to the government, thus avoiding responsibility for food safety concerns. These issues arise from an unbalanced relationship between government leadership and market regulations. Under the government franchising system, where competition is minimal or severely limited, ensuring quality becomes challenging. In the market environment, competition is always the main driver of continuous improvements in product quality, with consumers, acting as a primary regulator, creating positive feedback for the market. Government regulation can only play a supplementary supervisory role. Therefore, the formulation of pandemic prevention policies and the market should not be in opposition to each other. Pandemic prevention policies and intervention measures should be based on and built upon the market. Delegating the remaining responsibilities to the market once the government establishes its role as a regulator in times of emergency is advisable. For instance, in contrast to governments, retailers possess distribution network visibility, efficient and autonomous transport capabilities, sturdy distribution networks, and coordinated management (Manners-Bell, 2014). Hence, unless there is a comprehensive breakdown in the physical distribution system, the intricate supply chains established over time are poised to demonstrate optimal efficacy in the dissemination of various products (Manners-Bell, 2014).

Secondly, during emergency periods, legal frameworks and food safety systems may be incomplete. Due to the government confirming the list of supply guarantee enterprises based on Article 85 of the Chinese Procurement Law. This has led to several companies not qualified in the food services entering the food supply system. They did not have qualifications in food transportation and preservation. In food logistics, it is important to keep products moving in a safe, tamper-free environment while maintaining their quality (Dani, 2015).

However, they lack the necessary facilities for food quality control, such as temperature-controlled vehicles and specialized food storage containers. Food also must be stored in appropriate areas to prevent cross-contamination (Dani, 2015). Moreover, community committees and volunteers responsible for food distribution are not professionally trained in regulations, and their practices, thereby posing potential food safety hazards. Simultaneously, multiple food distribution procedures in the Shanghai food system might expose the food to environmental temperature changes, resulting in decreased food quality. To address this issue, firstly, it is essential to enhance emergency food safety laws and mechanisms by integrating food chain safety standards. This can ensure the safety qualifications of food suppliers. Secondly, utilizing existing technologies such as blockchain can be beneficial. Blockchain has proven effective in addressing issues of information opacity, lack of trust, and traceability in fresh food supply chains. It ensures the integrity and authenticity of supply chain information, enhancing overall transparency. Furthermore, it facilitates coordination with legislative bodies by providing the necessary documentation and data for importing cold chain products, thereby demonstrating the quality of the final products.

5.3 Urban food system resilience building

This study focuses on the challenges encountered by Shanghai and the measures taken to address them during the lockdown period. Firstly, Shanghai's ability to swiftly respond and ensure food supply for all individuals in a short timeframe despite the disruptions caused by the lockdown policy highlights its disaster resilience. The coherence of the system, smooth flow of information channels, and precise dissemination of information ensure that it can quickly connect various aspects within the system to form an emergency network. Furthermore, based on the challenges faced by Shanghai, we have identified two fundamental issues within the urban food system. Additionally, we have reflected on the shortcomings encountered in the solutions. These issues and deficiencies precisely highlight the areas where improvements are needed to enhance the resilience of the urban food system. Cities should strive for self-sufficiency as much as possible by enhancing internal spatial layout and planning, increasing urban agricultural production, and developing the disaster-resistant attributes of urban green spaces and gardens. They should also diversify food sourcing and shorten supply chains and establish emergency food networks rather than single chains. Emergency policies should be tailored to match the characteristics and functions of the food system. This requires greater involvement of experts in decision-making bodies and coordination with policymakers to establish more scientifically informed emergency policies. It can help avoid disruptions in the food chain caused by policy interference, resulting in prolonged transit times for food from the food chain to consumers. Government intervention should be based on market principles; although strong intervention may be effective in the short term, the emergence of monopolistic markets increasingly highlights issues of food quality. Emergency legislation should be further refined. While swift action during emergencies can provide immediate food sources for victims, if it overrides food safety regulations, it can lead to food safety issues and secondary harm to victims, such as the occurrence of foodborne diseases. With the rapid development of

artificial intelligence, big data, and blockchain, the dissemination and transmission of information will become faster and more accurate. Integrating these cutting-edge technologies into the construction of food system resilience will be more conducive to food safety supervision and clear accountability.

However, this study has some limitations. Firstly, it provides a macroscopic overview of the food supply solutions in Shanghai, neglecting the household dimensions of satisfaction and feedback on specific solutions. Future studies should examine residents to gain a deeper understanding of the practical effects of the solutions detailed and their opinions. Secondly, the data and information collected for this study were mainly obtained from the working records of government staff and some secondary information, potentially introducing subjective issues related to memory bias and descriptive accuracy.

6 Conclusion

In this study, we systematically present the challenges faced by Shanghai's food system during the lockdown, along with a series of solutions to address these challenges according to a food system framework. Our research initially conducted a Root Cause Analysis to identify four challenges faced by the food system in Shanghai during the lockdown period: lack of stable food supply and price, insufficient transportation capacity, lack of food access channels, and inadequate food security for vulnerable populations. Based on these challenges, we identified two fundamental causes of Shanghai's urban food system as (1) a disconnect between the functioning of the food system and the formulation of emergency policies and (2) reliance on external food supplies and low food self-sufficiency.

To address these challenges, Shanghai implemented a series of solutions, including contactless food delivery by trucks, a franchised food supply system to ensure uninterrupted food distribution, franchise systems coupled with collective purchasing to increase transportation efficiency and stabilize prices, opening up multiple purchasing channels to ensure food security for vulnerable populations, and the last-mile food delivery by community committees and volunteers. These measures were swiftly coordinated by the Shanghai government, linking community as the basic governance unit, and ensured food supply for 25 million people. This can be attributed to (1) systemic coherence and efficiency; (2) smooth information exchange channels; (3) accurate meeting of everyone's food needs. Furthermore, these measures are established within and aligned with the local culture and lifestyle, which contributes to their sustainability. However, these measures have also exposed two problems: (1) government intervention conflicting with the market, and (2) incomplete emergency legal frameworks and food safety systems. By addressing these two problems, we can improve the coordination between the government and the market, as well as the robustness of the food security system, thereby better preparing to effectively respond to various potential future shocks.

Although the implementation of policies and measures varies according to the cultural and political environment of each region, the goal of building resilient disaster food systems remains consistent. We expect that the challenges and solutions identified in Shanghai will

provide valuable lessons for urban food system development in other regions. These lessons are also important for strengthening the long-term resilience of food systems.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SH: Visualization, Funding acquisition, Resources, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Methodology, Conceptualization. LJ: Supervision, Writing – review & editing, Resources, Investigation, Formal analysis, Data curation. ZL: Validation, Methodology, Writing – review & editing, Supervision, Resources. KF: Formal analysis, Writing – review & editing, Supervision, Methodology. TI: Project administration, Writing – review & editing, Methodology. XZ: Writing – original draft, Supervision, Funding acquisition, Conceptualization, Writing – review & editing, Methodology.

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Conflict of interest

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Food environment in Burkina Faso: priority actions recommended to the government using Food-EPI tool

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Introduction: The food environment is an important factor in the efforts of countries worldwide to achieve a transition to sustainable food systems. The objective of this study is to formulate and prioritize actions to be addressed to the government of Burkina Faso for the creation of a healthy food environment, which will contribute to reducing malnutrition in all its forms and non-communicable diseases.

Methods: National experts were brought together to identify and prioritize actions to fill the gaps identified through a multi-step assessment process following the methodology of the Healthy Food and Environment Policy Index (Food-EPI).

Results: Up to 20 priority policy actions were recommended to the Burkina Faso government. Actions in the policy component focused mainly on regulation of food promotion and marketing, particularly to children, and others in the infrastructure support component focused largely on political leadership, i.e., strong and visible political support from the government to improve the food environment, population nutrition, diet-related non-communicable diseases and their inequalities.

Conclusion: The priority actions to be recommended to the government will strengthen advocacy for government decisions to create a healthier food environment in the country.

KEYWORDS

food environment, Food-EPI, food system, government actions, public policies, Burkina Faso

1 Introduction

Over the past decade, highly processed, energy-intensive, micronutrient-poor foods have become more promoted. They are accessible and inexpensive compared to less accessible fresh, minimally processed or unprocessed foods (1).

Nutritional transition is defined as changes in diets at the population level, corresponding to globalization and changes in a country's overall development, food environments and food systems. Risk factors such as poor-quality diet have always

been recognized as important for overweight and obesity (2, 3). These factors are incorporated into everyday life, partly as a result of various exposures, particularly the food environment (4).

The food environment, which is characterized by the physical, economic, political, and socio-cultural conditions that influence dietary decisions and marketing strategies, is a key factor in the spread of unhealthy eating, and a major risk factor for all forms of malnutrition (5–7). Burkina Faso's actual food environments are similar to those of the global food environment in that they do not support the consumption of healthy, sustainable diets and are therefore subject to increasingly high prevalence of all forms of malnutrition and non-communicable diseases.

Based on the 2021 Burkina Faso national nutrition survey, the prevalence of global acute malnutrition has fallen from 11.3% to 9.7% (including 0.8% in the severe form), chronic malnutrition from 35.1% to 21.6% and underweight from 26% to 17.5% (8). Overweight and obesity affected 0.9% and 0.2% of children respectively (8). The national prevalence of overweight and obesity among reproductive-age women in 2021 was 12.3% and 6.4% respectively (8). Among teenage girls aged 10 to 19, 0.6% were overweight and 4.7% obese. % (8). According to the report of the second national survey on the prevalence of the main common risk factors for non-communicable diseases in Burkina Faso, compared with 2013, the prevalence of obesity and overweight among men and women increased in 2021. It should be noted that after 2021, there are no national estimates because not all regions could be surveyed due to the security situation. In addition to these different forms of malnutrition, micronutrient deficiencies and the development of non-communicable diseases are still a major concern. The prevalence of anemia in children under five was 41% in 2020 (9). The prevalence of hypertension has risen from 17.6% to 18.2% and that of diabetes from 4.9% to 7.6% between 2013 and 2021 (10). However, the data from these results show that undernutrition and overnutrition coexist in the country, requiring the implementation of appropriate policies and programs to deal with them.

In a context where national governments are the main actors with the greatest capacity to change food environments and people's diets (11, 12), sustainable nutritional solutions therefore require appropriate policies and systems (13). Implementing effective policies can improve food environments, which in turn improve the nutritional status of the population and prevent overweight, obesity, and diet-related non-communicable diseases.

In Burkina Faso, the government's commitment to improving the nutritional status of the population through various measures is an expression of its interest in creating a healthy food environment. Indeed, in terms of food and nutrition policy, the country has recently set up a multi-sectoral and multi-disciplinary nutrition platform, which represents an opportunity to facilitate the evaluation of public policies and the promotion of political actions aimed at improving the nutrition of populations in Burkina Faso (14).

This study on food environments is a first in Burkina Faso, and has seen several innovations in the implementation of the Food EPI tool. A major innovation in this research is the addition of 12 new indicators taking into account the double nutritional burden, namely breastfeeding and complementary feeding, regulations on the marketing of breast-milk substitutes (MMS), national policies

to combat overweight, NCDs; undernourishment, health systems (growth monitoring); hygiene, water and sanitation (WASH); and sanitary safety (microbial and chemical contamination) (15). There is also an innovation in the methodology concerning the prioritization criteria in the process. In fact, 2 new criteria have been added, making it possible to take into account the gender and sustainability of the political actions to be prioritized for the creation of food environments.

The aim of this study was to formulate and prioritize policy actions relating to a healthy food environment in Burkina Faso, in order to reduce overweight, obesity, or non-communicable diseases. The first part of this paper describes the methodology applied, followed by the results presentation and discussion.

2 Methods

2.1 The socio-economic and demographic characteristics of Burkina Faso

Burkina Faso is a landlocked country located in the heart of West Africa. The country is exposed to a number of obstacles that hamper its economic development. The main factors limiting its development range from the precarity of rainfall to the remoteness of the sea, not to mention the low level of technology use in its agriculture sector that employs the majority of the population (30% of GDP, 80% of jobs).

According to the latest Census conducted in 2019, the literacy rate for people aged 15 and over was estimated at 29.7% nationwide, and 55.6% in urban areas compared to 18.5% in rural areas.

Based on the Human Development Index 2020 report, the country ranks 182 out of 189 countries, and according to the World Bank, 40.1% of the population lives below the poverty line (16). In terms of urbanization, Burkina Faso, like many developing countries, has experienced rapidly growing urbanization, from 6.4% in 1975 to 26.3% in 2019, although these urbanization rates remain among the lowest in the sub-region.

2.2 Study setting

This study used the healthy food environment policy index (Food-EPI) module developed in 2012 by the international network for food and obesity/non communicable diseases research, monitoring and action support (INFORMAS). This module comprises a tool and a process that have been designed to make inquiry on what progress the government has made in good practice to improve food environments and implement policies and actions to prevent obesity and non-communicable diseases (17, 18).

The implementation of the Food-EPI process may enable the identification and prioritization of government actions for the creation of food environments in Burkina Faso (17, 19). To accomplish this, the first step was to identify public policies and government actions using the Food-EPI tool, followed by a second step to assess the level of implementation of food environment and infrastructure support policies. This was followed by the implementation of the third step, in which key government

recommendations were identified and prioritized by a panel of multidisciplinary operational experts in the field of nutrition.

2.3 Data sources and collection

The tool and process established by the Food-EPI module was the theoretical framework that guided data collection and analysis for this study in Burkina Faso.

2.3.1 Food-EPI tool

The Food-EPI tool comprises seven policy domains representing key aspects of food environments: food composition, food labeling, food promotion, food pricing, food supply, food retailing and food trade and investment, and six infrastructure support domains: leadership, governance, finance and resources, monitoring, and evaluation, interaction platforms and health in all policies. The Food-EPI tool was adapted to the Burkinabe context by the research team in charge of implementing the tool in the country, contextualizing the original Food-EPI protocol (17).

Thus, the original 47-indicators tool has undergone some modifications. “3” indicators have been deleted: “2” indicators associated with “food retailing” and “1” indicator associated with “health in all policies.” These three indicators have been removed because they were similar to existing indicators.

The Food-EPI tool has been implemented in a number of sub-Saharan countries, including Ghana, Kenya and Senegal (20–22). A key recommendation from stakeholders involved in the Food-EPI process in these countries was to make Food-EPI indicators sensitive to the creation of healthy food environments to combat undernutrition (e.g., micronutrient deficiencies, stunting, and acute malnutrition), as these are a major public health problem in sub-Saharan Africa.

These new indicators are also in line with WHO recommendations for double-duty actions to combat all forms of malnutrition (15). Following these recommendations, in 2020 the INFORMAS team and researchers involved in research on food environments began the process of developing relevant indicators of undernutrition, to be included in the Food-EPI tool.

Then, 12 new double burden of malnutrition indicators have been added, relating to breastfeeding and complementary feeding, regulations on the marketing of breast-milk substitutes, national policies to combat overweight, NCDs and undernutrition, health systems (growth monitoring), water, sanitation, and hygiene (WASH) indicators, food retailers, and traders (hygiene and sanitation), and health safety (microbial and chemical contamination) (23). The final Food-EPI tool in Burkina Faso comprised 56 indicators grouped into 13 policy and infrastructure support domains (Figure 1) (see details in Appendix 1).

2.3.2 Food-EPI implementation process

The process was divided into six steps, which have been implemented in previous studies (24, 25), with the exception of the last two steps concerning the formulation and prioritization of actions, which was the subject of this study (Figure 2). Afterwards, evidence on the implementation of public policies and government

actions was collected, summarized in an evidence document and verified by government staff in Burkina Faso.

Information collected on policies and governmental actions during the implementation of the Food-Epi process and used as secondary data in this study included: (1) Policy documents: policy guidelines on nutrition and health or legislations (law or decree) in the field of nutrition; (2) Strategic documents: documents outlining political or strategic axes or operationalizing policy guidelines; and (3) Operational documents comprising: (a) reports on the activities of various sectors that are sensitive or specific to nutrition, (b) reports on national nutrition or health surveys, and (c) nutrition programs and food-related guides.

On the basis of this evidence document, the level of implementation of food environmental policies was assessed against international examples of good practice. Following this final assessment, actions recommended to the government were formulated by experts and prioritized according to their importance, feasibility, effect on double burden, gender and sustainability.

2.3.3 Panel of expert evaluators

In line with Food-EPI's methodology, the process of identifying and prioritizing actions was organized throughout a physical presence workshop.

In order to formulate and prioritize the actions to be recommended to governments, the invited participants to this workshop were selected according to their field of expertise, while ensuring that they had already participated in the majority of steps in the overall Food-EPI process. These expert evaluators were from universities, government organizations, civil society, and Non-Governmental Organizations involved in public health and/or nutrition.

2.4 Identifying and prioritizing actions

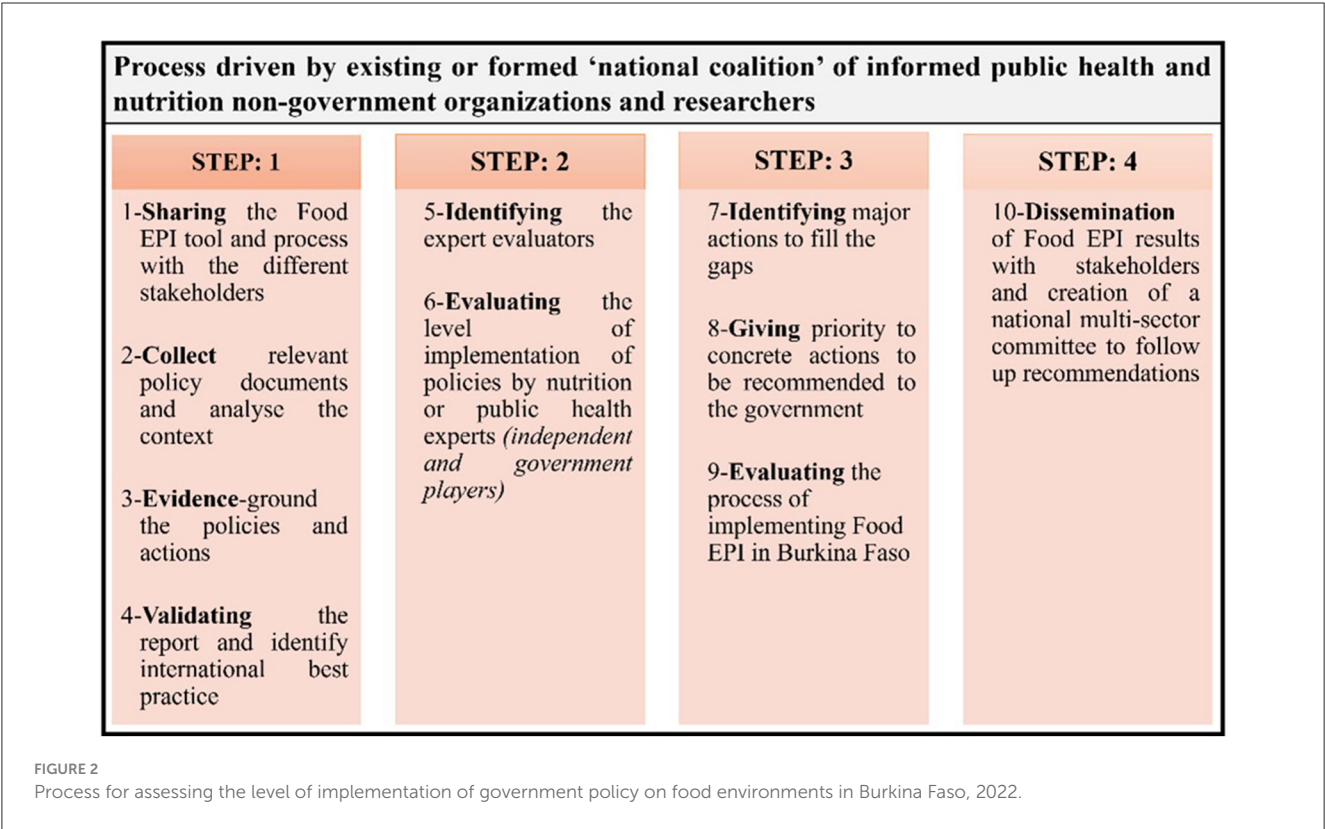
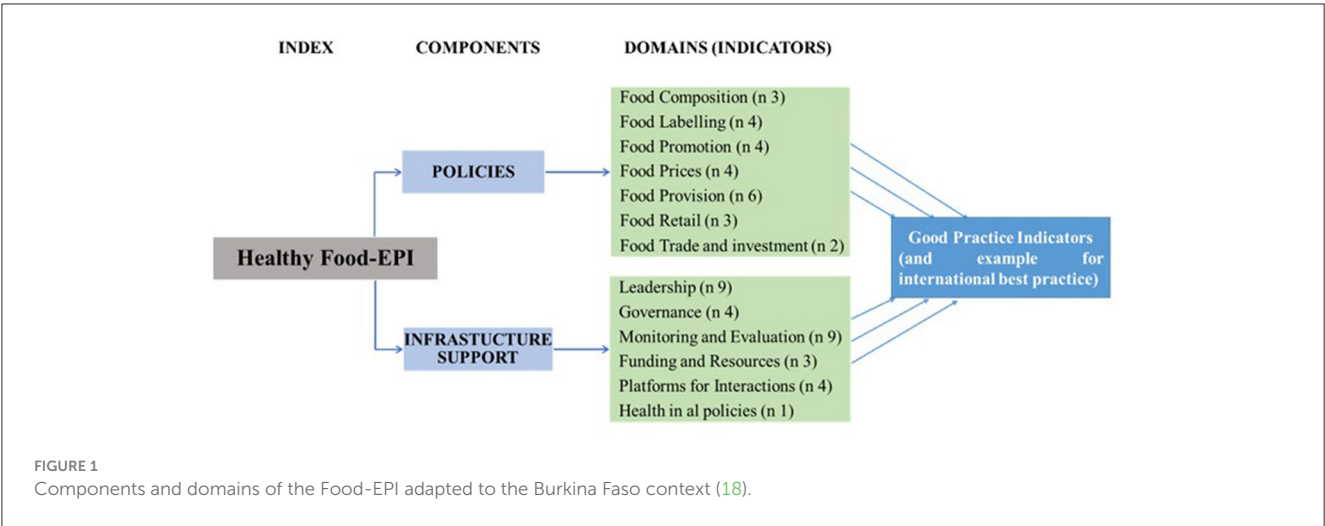
The process of identifying and prioritizing actions took the form of three-step workshops: first, the identification, then the prioritization of actions, and finally the priority actions to be recommended to the government.

2.4.1 Action identification process

This step was a 1-day workshop, during which the results of the assessment of the level of implementation of policy was presented, in order to facilitate the identification and formulation of actions.

The main outcome was the selection of actions to fill identified gaps in policy implementation, to reinforce already implemented policy actions, or to select actions that could address the problems of undernourishment by improving food environments. This identification of actions was carried out by two mixed working groups. Each group identified actions by component, leaving it to each group to decide whether an indicator should include several actions or none at all.

At the end of this step, the identified actions by each group were presented and discussed, and a common list of concrete actions to be prioritized was validated by all the experts.



2.4.2 Action prioritization process

This step followed that of formulating actions and consisted in prioritizing individually the actions by each expert, using a Likert scale from 1 to 5. This prioritization of validated actions was carried out according to five criteria (Table 1): (i) importance of the action, (ii) capacity to carry out the action, (iii) potential effect of the action on double burden, (iv) potential effect of the action on gender and (v) potential effect of the action on sustainability.

An interesting outcome was found in the implementation of Food-EPI in Burkina Faso. Indeed, in addition to the two initial criteria (C1 and C2) of the Food-EPI module and one introduced during the implementation of Food-EPI in Senegal (C3) (22),

this study introduced two new prioritization criteria (C4 and C5). These criteria took into account the potential effect of the action on gender and sustainability, which are two public health issues strongly influenced by socio-economic, demographic and climate change.

2.4.3 Actions to be recommended to the government

After prioritizing the actions on the basis on the five criteria, a final step determined the main actions to be recommended to the government.

TABLE 1 Criteria for prioritizing actions to be recommended to the government.

Criterion 1 (C1): importance	1. Need: Size of implementation gap 2. Impact: the effectiveness of the action in improving food environments 3. Effects on equity and other positive or negative effects of the action: ✓ Equity: Progressive/regressive effects on reducing health inequalities linked to food and diet. ✓ Other positive effects (example): Protection of children's and consumers' rights ✓ Negative effects (example): regressive effects on household income or violation of personal freedoms
Criterion 2 (C2): ability to perform	1. Feasibility: How easy or difficult will it be to implement the action? 2. Acceptability: The level of support from key stakeholders (government, public, public health and industry). 3. Affordability: The cost of implementing the action
Criterion 3 (C3): potential impact of the action on the double burden of malnutrition	1. Beneficial effect: Implementation of the action has a beneficial effect on the double burden of malnutrition 2. Aggravating effect: Implementation of the action increases the risk of other forms of malnutrition or NCDs 3. Neutral effect: Implementation of the action has no effect on increasing the risk of other forms of malnutrition or NCDs.
Criterion 4 (C4): potential gender impact of the action	1. Beneficial effect: Implementation of the action has a beneficial effect on gender. 2. Aggravating effect: Implementation of the action increases the risk of other forms of gender inequality 3. Neutral effect: The implementation of the action has no effect on gender inequalities.
Criterion 5 (C5): potential impact of the action on sustainability	1. Beneficial effect: Implementation of the action has a beneficial effect on sustainability. 2. Aggravating effect: Implementation of the action increases the risk of adverse effects on sustainability 3. Neutral effect: Implementation of the action has no effect on sustainability.

This was the step of disseminating the results. This final stage in the implementation process of the Food-EPI research project will be carried out in the form of a workshop, and will provide an opportunity to synthesize the data from the results of the identification and prioritization step.

At this step, the actions to be recommended to the government will be gone through, and in a common consensus with the parties involved they will be reformulated or combined in order to broadly take into account all the needs. Then 20 priority actions based on all the criteria will be validated, among which 10 from policy component actions and 10 from infrastructure support actions.

2.5 Data analysis

Descriptive statistics performed using Microsoft Excel 2021. To prioritize proposed actions, individual scores were assigned to the importance, feasibility, and potential effect of the action on the double burden of malnutrition, gender and sustainability.

The average scores for each criteria was then merged for each action to determine a single criteria corresponding to “priority actions.” In this way, actions were classified from the highest to lowest priority.

2.6 Ethical considerations

This study was reviewed and approved by the Burkina Faso health research ethics committee under deliberation no. 2021-04-112. In order to facilitate data collection, an administrative letter was sent by the Ministry of Health through the Technical Secretariat in charge of multisectoral nutrition to all the ministries concerned. All ministries and stakeholders involved in nutrition were informed of the purpose of the study. The ethical consideration was taken into account by respecting the anonymity of the actors during data analysis.

3 Results

3.1 Expert evaluators

Among 56 invited participants, 40 expert evaluators were physically present, giving a participation rate of 71.4%. Among evaluators, 17 were independent stakeholders and 23 were staff from government.

3.2 Policy actions and support for identified and prioritized infrastructures

After calculating the average score for each of the actions prioritized by all the experts (see details in [Appendix 2](#)), they were ranked in descending order according to the average score obtained by adding together the five prioritization criteria. Each action was ranked according to all criteria, from the most important action, with a high capacity for implementation, a high potential beneficial effect on the double burden, gender and sustainability, to the least important action, with a low capacity for implementation, a low potential effect on the double burden, gender and sustainability.

This workshop was held from June 20 to 21, 2022 and the expert evaluators identified 123 priority actions to improve the food environment in Burkina Faso, including 70 actions under the “policy” component and 53 actions under the “infrastructure support” component (see details in [Appendix 2](#)). These identified policy actions concerned all macro and micro level.

3.3 Actions to be recommended to the government

Based on the five criteria used in this study, 10 priority actions from each component to be recommended to the government were selected by mutual agreement, taking into account the experts' perception of the importance, feasibility,

potential effect on the double burden of malnutrition, gender and sustainability of these actions in Burkina Faso (Tables 2, 3).

In the policy component, 10 selected priority actions from the 70 policy actions were identified (Table 2).

In the infrastructure support component, 10 selected priority actions were identified out from the 53 infrastructure support actions (Table 3).

4 Discussion

In West Africa, Ghana and Senegal have implemented studies following the results of Food EPI implementation recommendations. In Ghana, for example, two studies were carried out, one on food promotion (commercial food advertising on the campus of Ghana's largest university) and the other on commercial food advertising (food health on the promotional leaflets of fast-food outlets located in Accra's shopping malls). And in Senegal, following on from the Food EPI study, the national consumption survey has been carried out and the data will be released shortly. In addition, a study is currently being carried out on food promotion (exposure of school-age children to unhealthy food advertising in public and media spaces in urban Senegal).

In Burkina Faso, previous analysis of the level of implementation of Food-EPI indicators has identified priority actions targeting gaps in policy or infrastructure implementation. This enabled to evaluate the priorities suggested for the government's future action. Indeed, the experts reached a consensus on the priority actions to be implemented by the government of Burkina Faso, and 123 actions were prioritized, out of them, 10 in policy and 10 in infrastructure support were judged to be the most important, the most feasible and to have a beneficial effect on the double burden of malnutrition, gender and sustainability.

4.1 Policy component

Although the prioritization of actions is specific to each country, the priority policy actions above from our study are almost similar to those in Senegal, Ghana and Kenya. Indeed, in these countries, the priority actions selected included raising taxes on unhealthy foods, limiting the promotion of unhealthy foods to children (through broadcast media, non-broadcast media, and rallies), front-of-pack labeling and compositional targets for processed foods, and healthy school food policies (26).

It's also important to note that over forty jurisdictions in more than twenty countries have introduced taxes on sugary drinks, and at least eighteen countries have imposed mandatory restrictions on the advertising of unhealthy foods to children via broadcast or non-broadcast media (11). In view of the impact of food promotion on dietary behavior and consequently on public health, the need to tackle food promotion targeting children must be reinforced (27). Various reports indicate that intensive

marketing of fast food and energy-dense, nutrient-poor foods and beverages is a "possible" cause of weight gain and obesity in children (27, 28).

The academic, civil society and public sector experts involved in this study can make a significant contribution to creating a healthy food environment in Burkina Faso by implementing the study's recommendations (11). However, conflicts of interest in the food sector may limit the active participation of some actors in decision-making (29, 30). For this reason, in Burkina Faso, a continuous and extended dialogue between all parties involved, including representatives of the food industry, would be most advisable.

These actions mainly fill major gaps in the country concerning the provision of access to potable water and sanitation, regulations on food promotion and marketing, particularly to children, the introduction of nutrition and food-related subjects in educational establishments, and the importance of providing healthy school meals. In Burkina Faso, current law outlines general provisions, but does not specifically consider the impact of advertising unhealthy foods to children through broadcast or non-broadcast media (31). There is a lack of policies that clearly define which foods are allowed for advertising or in the school environment and which are not. However, these recommended actions will in part enable Burkina Faso to improve the food environment for children, as school food environments have previously been associated with spaces that can offer children the opportunity to develop healthy eating habits that can be transferred to adulthood (32).

In addition, the government should take actions for children under 6 months of age, to enable mothers to benefit from favorable conditions and carry out exclusive breastfeeding until the child is 6 months old, as suggested by the World Health Organization. Several strategies are being deployed in Burkina Faso to promote exclusive breastfeeding and all aspects of regulations on breast-milk substitutes, however, these actions can be reinforced. These include the "stronger with breast milk only" campaign, which aims to mobilize partners, businesses, communities and families to ensure that mothers receive the appropriate information and support they need to adopt exclusive breastfeeding and give their children the best start in life (33). Burkina Faso also has laws and policies governing maternity leave and the protection of pregnant women, based on international labor organization conventions. Indeed, in Burkina Faso two laws include provisions on maternity leave (34) (law 028-2008/AN of May 13, 2008 on labor code and law 081-2015/CNT of November 24, 2015 on the general status of the state civil service).

The priority action to be implemented is to strengthen the provision of access to potable water and sanitation services in line with national standards, because access to potable water, hygiene, and sanitation services remains limited due to the dramatic consequences of the security crisis the country is experiencing. In addition, even if the actors involved are making efforts, the rate of progress toward achieving the objectives, particularly with regard to sanitation, remains low. Added to this is the practice of open defecation, which is still widespread and persistent in communities (35).

The actions to be recommended to the government concerning the composition of foodstuffs specifically include: (i) mandatory

TABLE 2 Priority policy actions according to all criteria to be recommended to the government of Burkina Faso, 2023.

Order number	Indicators concerned	Priority actions recommended to the government
1	PROMO 1: Restricting the promotion of unhealthy foods: audiovisual media PROMO 2: Restricting the promotion of unhealthy foods: non-broadcast media PROMO 3: Restricting the promotion of unhealthy foods: Children's environment	Elaborate regulations prohibiting the advertising/promotion of unhealthy foods in children's living environments (schools, sports grounds, playgrounds), in the audiovisual media and in the non-broadcast media.
2	COMP 3: Obligatory food enrichment programs	Making it an obligation to comply with food standards, in particular for infant formula and packaged water
3	PROV 6: National policy to promote access to WASH	Reinforce the provision of drinking water and sanitation services in line with national standards
4	PROV 5: Policies and/or regulations facilitating breastfeeding	Creating space in workplaces to make it easier to look after infants
5	COMP 3: Obligatory food enrichment programs	Adopt a monitoring plan for food enrichment programs, including infant flour
6	PROV 1: Education policies encourage healthy food choices	Increase the supply of varied and balanced meals based on local produce in school canteens
7	PROV 1: Education policies encourage healthy food choices	Reinforce the inclusion of nutrition education in curricula and its promotion in schools
8	PROV 5: Policies and/or regulations facilitating breastfeeding	Increase the duration of breastfeeding hours from one and a half hours per day to 3 hours per day for breastfeeding mothers aged between 0 and 6 months.
9	PROMO 4: Policies restricting the marketing of Breastmilk Substitutes/broadcast and non-broadcast media	Effective application of current legislation on breast-milk substitutes
10	TRADE 2: Protecting regulatory capacity - nutrition	Systematic monitoring (health parameters) of stocks of food of animal origin entering the territory

TABLE 3 Priority infrastructure support actions across all criteria to be recommended to the Burkina Faso government, 2023.

Order number	Indicators concerned	Priority actions to be recommended to the government
1	LEAD 6: National breastfeeding Policy	Reinforcing the transition to the scale of infant and young child nutrition
2	LEAD 2: Dietary intake targets for the population are defined	Dietary intake targets for the population are defined
3	LEAD 1: Strong, visible political support	Constitutionalizing the right to healthy, varied and balanced food
4	LEAD 9: Strong and visible political support for undernourishment	Reinforcing actions to fight malnutrition
5	LEAD 1: Strong, visible political support	Increase the line's budget allocation for nutrition
6	LEAD 3: Implemented food guidelines	Doing a food consumption survey followed by national dietary recommendations
7	MONIT 2: Monitoring nutritional status and food intake	Assess the level of implementation of good hygiene practices in school canteens and community restaurants
8	MONIT 9: Food safety indicators and standards are defined and monitored	Elaborate a regulatory text on Food Safety
9	GOVER 3: Transparency for the public in the development of food policies	Reinforcing the inclusive process in the development of food and nutrition policies
10	MONIT 7: Indicators on breastfeeding and complementary breastfeeding monitored	Reinforce actions implemented in connection with complementary food

compliance with food standards, in particular for infant formula and packaged water, and (ii) the adoption of a monitoring plan for food fortification programs, including infant formula. These actions will highlight the importance the country attaches to compulsory food fortification programs, particularly as regards infant flour, since providing young children with a porridge of good

bacteriological and nutritional quality is a means of improving the nutritional status of developing countries (36). In addition, small-scale infant meal production companies are emerging in many developing countries, making it crucial to assess these products from a normative point of view to ensure their survival and positive impact on the quality of infant nutrition.

As far as trade and investment are concerned, the government has been recommended to carry out systematic checks (health parameters) on stocks of animal products entering the country. It is important for the government to adopt measures to manage investments and protect its regulatory capacity in the public health nutrition field.

4.2 Infrastructure support component

These actions from the infrastructure support component to be recommended to the Burkinabe government will mainly address gaps in nutrition policy leadership, more specifically in the fight against malnutrition, food guidelines and nutrition financing. Government monitoring and evaluation systems and governance are among the priority domains for which efforts will need to be made in terms of food and nutrition policy development, food safety and good hygiene practices.

Even though Burkina Faso has had a plan for scaling up the promotion of optimal infant and young child feeding practices (2013–2025) since 2013, it has to be said that there are still many efforts to be made, as of April 2021, only 8 of the country's thirteen regions were covered, with varying levels of implementation.

In terms of political leadership, one of the actions focuses on the constitutionalization of the right to a healthy, diversified and balanced diet. According to the WHO, the right to adequate food goes beyond kilocalories. Everyone should have permanent access to healthy, nutritious and culturally acceptable food (37). The SUN (Scaling Up Nutrition) movement, founded on the principle that everyone has the right to food and good nutrition, campaigns for nutrition to be considered a priority on the national political agenda, a cause that has reached many new member countries, such as Burkina Faso in 2011 (38).

According to WHO/UNICEF recommendations, the initiation of early breastfeeding and exclusive breastfeeding are optimal practices whose impact on the survival, growth and development of infants and young children has a significant impact on the overall reduction of neonatal mortality.

In this context, the actions to be recommended to the government concerning the reinforcement of the scaling-up of Infant and Young Child Feeding and the strengthening of actions implemented in the fight against malnutrition will thus enable Burkina Faso, among other things, to achieve its objectives of reducing stunting in children aged under 5 by 2025.

As for the last two actions to be recommended to the government concerning the country's political leadership, these relate to the development of a national food composition table and the carrying out of a food consumption survey followed by national dietary recommendations. These two actions are timely recommendations to the government, as Burkina Faso has not set clear dietary intake targets for its population in terms of nutritional elements of concern, in order to meet WHO recommended dietary intake levels. Also, the non-constant frequency of population surveys (STEPS survey: WHO survey of NCDs risk factors 2013 and

The National Iodine and Anemia Survey 2014) was not conducive to an understanding of consumption levels of nutritional elements of concern. With regard to dietary guidelines, WHO recommends that countries implement cross-sectoral, multidisciplinary national policies and action plans aimed at reducing consumption of nutrients of concern (sodium, sugar, and fat), and develop national dietary guidelines 20–22 (39–41). Some African countries, such as Benin, Ghana and Kenya, have their own national dietary guidelines. In Brazil, the Minister of Health has shown leadership by developing new dietary recommendations that are radically different from most of the recommendations developed to date in other countries, and is one of the most widely cited health recommendations. Burkina Faso should also follow the example of some African countries and develop its own national dietary recommendations and guidelines based on food consumption surveys.

A final priority action of political leadership to be recommended to the government concerns a reinforcement of the budget allocation of the nutrition line in Burkina Faso. Promoting the issue of nutrition requires significant and appropriate financial investment, as well as efficient use of available resources.

Donors do not have the resources to meet development challenges on all fronts. Thus, there is an increasingly urgent need to mobilize domestic resources, which means encouraging authorities in developing countries to invest local resources in human capital (i.e., health, nutrition, and education). In Burkina Faso, the government made commitments in 2021 concerning the financing of nutrition at the Nutrition for Growth (N4G) summit, these include (42): increasing spending on nutrition by technical and financial partners from 4% between 2016 and 2018 to at least 10% between 2018 and 2024; zero-rating products used in malnutrition prevention and management inputs by 2024 in 2018 to at least 3% of the national budget by 2024; and increasing the State's contribution to nutrition to 3% (2021).

The three actions relating to monitoring and evaluation systems include a suggestion to the government relate firstly to: evaluate the level of implementation of good hygiene practices in school canteens and community restaurants; carrying out this action will enable the government to ensure that school canteens and community restaurants comply with good hygiene practices. The next step is to draw up a regulatory text on food safety. This action represents a logical follow-up to the political will to reinforce and improve the state of food safety. Indeed, the existence of the national food safety emergency response plan is fully in line with the multi-sectoral national nutrition policy (2020–2029), which gives pride of place to its axis 4 on strengthening food safety. The national food safety emergency response plan is a reference for the competent authority in implementing responses to food safety emergencies (43). The process has already begun at the executive secretariat of the national food safety council, with the support of the African union commission. In conjunction with this is a country food safety profile document, the process of which has already begun at the executive secretariat of the national food safety council, with the support of the African union commission. Finally, the last action concerns the reinforcement of

actions implemented in connection with complementary feeding. Increasingly convincing scientific studies show that during the first 1,000 days of life, nutrition, lifestyle habits and other environmental elements have a significant impact on physiology, function, health and future performance. Thus, during the first 2 years of life, it is essential to implement healthy feeding practices for infants to promote healthy growth (44).

With regard to this action in Burkina Faso, there is the Scaling-up plan for the promotion of optimal infant and young child feeding practices (2013–2025), which monitors breastfeeding and complementary feeding indicators (45). Added to this in Burkina Faso there is a communication strategy for social and behavioral change in favor of dietary diversification for children aged 6–23 months. Added to this in Burkina Faso there is a communication strategy for social and behavioral change in favor of dietary diversification for children aged 6–23 months. However, several actions can be implemented, following the example of Asia Pacific, which developed a guideline on complementary nutrition for the Asia-Pacific region during 2020. Kenya and Zambia have also developed complementary food recipe books in their countries (46).

In terms of governance, the action suggested to the government is to strengthen the inclusive process in the development of food and nutrition policies. Indeed, in the policy documents available and accessible in Burkina Faso, none has made it possible to find documented and inclusive actions that value the use of community opinions in the development of food and nutrition policies. However, the multi-sectoral approach is a mechanism which, when implemented, enables the opinions of each informed sector to be gathered more widely during the process of developing certain national food policies. Thus, through decree N°2017/958/MS/CAB concerning the creation, composition, attributions and functioning of Functional Team 5 “multisectoral nutrition management,” the creation of the functional team with the provision of focal points in the various sensitive and specific nutrition sectors makes it possible to have accurate data and information (47).

4.3 Limits and strengths

The strength of the approach lies in the use of the Food-EPI tool, which is a rigorous, comprehensive and internationally harmonized methodological framework. It enables an in-depth analysis of the current policy landscape on food environments in the country where it is implemented, and the presence of multi-disciplinary and multi-sectoral stakeholders in the evaluators contributes to government ownership of the results. Added to this is the introduction of two new prioritization criteria to consider gender and sustainability in the actions to be recommended to the government.

The main limitation of the approach used is the sample size, but it may well compare well with similar studies carried out in other countries. Participants were identified according to their skills, and some state actors were replaced by others throughout the process, making the groups less homogeneous than groups of independent actors. Finally, the time devoted to prioritizing actions according to the established criteria was insufficient, because of the number of

actions to be prioritized, and also because of the difficulty for the experts to prioritize the importance of the actions, due to the fact that they are equivalent.

5 Conclusions

This final step in prioritizing actions to create healthy food environments in Burkina Faso, using the Food-EPI tool, focuses on the efforts needed to improve the safety of the food environment.

In terms of the policy component, it is essential to guarantee access to potable water and sanitation, put in place regulations on food promotion and marketing, particularly for children, introduce nutrition, and food-related subjects into educational establishments, and focus on the provision of healthy food in schools. For the infrastructure support component, priority initiatives focus on political leadership in nutrition, with an accent on the fight against malnutrition, dietary recommendations, and nutrition financing. Governance and governmental monitoring and evaluation systems are essential areas in which efforts will need to be made, particularly with regard to the development of food and nutrition policies, food safety and governance.

For the government to implement these actions, a wide variety of actors, including political decision-makers, civil society, and academia, will be important.

The implementation of Food-EPI in Burkina Faso was useful in developing a consensus for priority action supported by a group of national experts for the creation of healthy food environments in the country. This study represents the latest step in the evaluation of public policies and government actions for the creation of healthy food environments in Burkina Faso using the Food-EPI tool. It highlights required efforts to improve the healthiness of the food environment by identifying and prioritizing actions for healthier food environment in the country.

The activities performed the government are ambitious, and can only be efficient through cooperation between public and non-public actors.

This contribution supports calls for a healthier food environment, and helps strengthen the government's support for decisions to create a healthier food environment.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Author contributions

VT: Validation, Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Investigation. CE: Conceptualization, Data curation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft. AZ: Conceptualization, Data curation, Methodology,

Project administration, Supervision, Validation, Writing – original draft, Resources. JS: Conceptualization, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Data curation. JM: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft. AD: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft. J-CM: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft. SV: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft. MD: Resources, Supervision, Validation, Writing – original draft, Formal analysis.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2024.1420323/full#supplementary-material>

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Food waste awareness among Italian university students: results of an online survey

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Introduction: Food waste (FW) represents a significant social and environmental problem, with 1.3 billion tons of food wasted yearly worldwide. Even if consumers are increasingly aware of the phenomenon, it remains relevant, and understanding the behaviors of specific target audience segments appears instrumental to the planning of effective interventions. To this end, we designed an observational study to investigate, throughout an online questionnaire, FW-related habits of university students in a Southern Italian region.

Methods: A representative sample of 431 students from the University of Catanzaro Magna Graecia completed an online survey aimed at investigate FW related behaviors. A descriptive analysis was performed on the whole cohort, and a formal statistical analysis was carried out after excluding responders who had not correctly followed the survey instructions ($n = 85$). Differences were assessed by chi square (χ^2) tests. A food wasting score was generated, and differences in the score values were analyzed by Student *T*-test. Linear and multiple regression analyses were performed to identify factors contributing to the score.

Results: Overall, the results of our survey show a high prevalence of virtuous behaviors in the food purchasing phase; while, at home, less than 50% of respondents apply easy-to-implement waste prevention rules. The statistical analysis showed that the major determinants of FW were: no direct involvement in grocery shopping and male gender. Indeed, even if we observed several significant differences comparing subgroups based on established or putative determinants of FW behaviors, none survived matching for group size, gender and relevant food managing (shopping, storing, cooking) habits. The only exception was the more appropriate handling of “use by” products by respondents who received structured nutrition teaching, as opposed to students whose academic courses do not include this subject (adjusted $p = 0.008$).

Conclusion: Our data suggest that young adults are trying to implement strategies to reduce FW, even if there is room for improvement, particularly in the storage phase. Extending nutrition education to all university programs may be helpful in reaching this goal.

KEYWORDS

gender related differences, education, waste management and disposal, university student behavior, expiration date monitoring

1 Introduction

Food waste (FW) represents a significant social and environmental problem; it is defined as all comestible materials within the food reserve that are intended for human ingestion but are not consumed (1). FW not only results in wasted resources and avoidable environmental impact but has also an important cost for human health since wasted food represent nutrients and energy that could have provided nutritional benefits (2).

Every year, 1.3 billion tons of food are lost or wasted worldwide (3); the amount of FW is, however, different in every country and region. For example, consumers from Europe and North America waste a larger amount of food than consumers in sub-Saharan Africa and South/Southeast Asia (95–115 kg *per capita* per year vs. 6–11 kg *per capita* per year, respectively). It has been estimated that the total amount of waste generated by consumers in developed countries every year (222 billion kg) approximately equals the total amount of annual food production in sub-Saharan Africa (230 billion kg) (2). If we focus on Italy, the Southern Italian Regions present lower incidence of FW than Central or Northern regions (4).

FW occurs mainly at the later stages of the food supply chain, such as the retail and consumption phases. According to the Food Waste Index Report 2024 of the United Nations Environment Programme (UNEP), in 2022, 12% of the total waste was generated by retail vendors, 28% by food services, while 60% was due to households (5). Interestingly, it has been suggested that consumers also indirectly cause FW because the supply chain assumes that they demand perfect cosmetic quality related to the shape, size, and appearance of food products, which leads to waste in the primary production stage of the food chain (6).

In recent years, consumers are becoming increasingly aware of their role in preventing FW; however, despite the implementation of national programs aimed at addressing it, including the so-called Good Samaritan Law (155/2003) in Italy (7), the phenomenon remains relevant.

The European Union (EU) Platform on Food Losses and Food Waste has underlined the importance of understanding the behaviors and motivations of specific target audience segments to gain insights into obstacles to behavioral changes and plan more effective interventions (8).

Young adults, such as those attending university courses, represent an ideal population since they are usually more environmentally conscious than older generations, they can be more easily reached by intervention programs, and they are more likely to adopt behavioral changes. Up to 80% of the literature in the field of food-related habits is indeed based on students cohorts, according to a recent review (9); among these, there are studies carried out in Italy (10–15), particularly in the Southern regions of the country (11, 13, 15), as well as studies specifically addressing FW-related behaviors (10, 16, 17). However, to the best of our knowledge, the only studies directly addressing FW in an Italian cohort date to almost a decade ago and examined data from comparatively small ($n=180$ and $n=233$, respectively) groups of students living in Lazio, a Central Italian region (10, 12). We thus designed this observational, pilot study to investigate FW-related habits of students attending the University of Catanzaro Magna Graecia in Calabria, a Southern Italian region. While the mediterranean area has a solid tradition of healthy eating and a strongly rooted food culture (18), in more recent years, North–South and older adults–younger subjects

decreasing gradients of nutrition literacy have been reported (19); our study will thus also contribute to this debate.

2 Methods

2.1 Questionnaire and survey methodology

A sample of $n=431$ students enrolled in academic programs at the University of Catanzaro Magna Graecia, completed an online survey between November 22nd 2022, and February 7th, 2023, aimed to investigate FW-related behaviors (Supplementary Figure S1). Students were invited to participate in the survey during regular frontal lessons on subjects related as well as unrelated to nutrition issues; participants were also asked to disseminate the questionnaire among their friends and peers (snowball sampling technique). Students from all academic programs offered by the University of Catanzaro Magna Graecia participated to the survey. A short statement explaining the survey purpose, the planned use of the data, reporting the eligibility criteria (i.e., to be 18 years or older and enrolled at the University of Catanzaro Magna Graecia), as well as stating that the data were anonymous and that the completion of the study would indicate consent, was included at the beginning of the survey. Each user could fill in the questionnaire only once. E-mail addresses were not recorded and were not visible to the study investigators to ensure anonymity. The Magna Graecia University Ethics Committee (Comitato Etico Azienda Ospedaliera “Mater Domini”) assessed the questionnaire and concluded that formal approval was not necessary because answers were anonymous and non-sensitive data only were collected.

The questionnaire included 23 one-option or multiple choices questions structured in 6 different sections. A translation of the Italian version, which was employed in the study, is available as Supplementary material. All questions have been developed by the study investigators since none of the questionnaires employed in previous studies were developed for our target population. Specifically, the survey was developed by one of the senior authors (MLH), and subsequently amended by another senior author (AP). The survey was then taken by the two youngest authors (FC and VC) who suggested a couple of improvements, and by a small group ($n=15$) of students enrolled in the third final year of the dietetics degree course whose answers were not included in the final cohort (Supplementary Figure S1). The initial section (A) covered sociodemographic information such as age, gender, academic formation and living situation. Section B contained questions regarding grocery shopping, food storage and cooking habits; section C included a set of questions aimed at evaluating behaviors during the shopping phase; section D questions were devoted to the food storage phase; while section E questions were related to the meal preparation and handling stages. Finally, section F comprised questions related to waste and recycling. Three questions (Q7, Q13, and Q15) offered an “open answer” option; however, given the small number of individuals choosing this option, their responses were merged with the more similar fixed one for analysis purposes. The only mandatory questions were those in section B; therefore, the total number of responses was slightly different for some questions, both in the whole population and in the sample retained after omitting the respondents who did not follow the questionnaire instructions. The time required to complete the questionnaire ranged from 2 to 10 min (medium time: 4 min).

2.2 Statistical analysis

Data were analyzed using descriptive analysis and are expressed as relative frequencies or as mean $\pm$ standard deviation (SD), as appropriate. A formal statistical comparison was carried out after excluding respondents who answered questions that they were supposed to skip according to questionnaire instructions (i.e., Q8–11 with D or E for Q5, Q12–15 with C, D or E for Q6, Q16–19 with D, E or F for Q7). The retained sample included 346 students (Supplementary Figure S1). There were no significant differences in the characteristics of the excluded subjects for Q1–4. In addition, to simplify the interpretation of the results, we coded the responses to Q3 as follows: Q3.1 students enrolled in a biomedical area program vs. students enrolled in a program from a non-biomedical field; Q3.2: students enrolled in a program comprising at least one nutrition course vs. students enrolled in a program that does not include structured nutrition teaching. We also merged the responses to Q4 as follows: Q4.1 students living with their family of origin (old living situation) vs. students living in a new household (alone, spouse/partner with or without children, other students, etc.); Q4.2 students living with either their family of origin or their new family (spouse/partner and children) vs. students in other living situations (alone, spouse/partner without children, other students). Differences between groups were assessed by chi square (χ^2) tests. A food wasting score was generated assigning 0 to 3 points for responses to questions Q8–19. Differences in the score values were analyzed by Student *T*-test. Linear and multiple regression analyses were performed to identify factors contributing to the score (Supplementary Figure S1). A *p*-value < 0.05 was considered statistically significant in all analyses. All analyses were performed using Jamovi 2.3.21 software version.

3 Results

The results of our survey suggest a good prevalence of FW-reducing habits in our cohort: particularly, 252 respondents (67.7% of the whole cohort) always checked expiration dates and 237 (63.7%) declared to use a written list or a weekly menu, while grocery shopping (Figure 1). By contrast, a suboptimal percentage of the respondents stored food products according to their expiration dates or to any criterion aimed at reducing the risk of letting products go past their expiration date (Q12: $n = 187$, 46.7%; Q13: $n = 174$, 43.5%; Q14: $n = 131$, 32.9%) and a surprisingly high number of individuals ($n = 189$, 47.3%) relied only on their memory and ability to carefully plan food purchases and did not register expiration dates when removing products (e.g., eggs) from their original packaging (Figures 2, 3).

The mean age of the 431 respondents was 22.4 ± 3.34 (range 18–47); as expected, the majority of the sample (69.4%, $n = 298$) was in the 20–23 years old (y/o) range, with only 34 (7.9%) younger individuals (18 y/o, $n = 4$; 19 y/o: $n = 30$); 69 (16%) subjects were in the 24–26 y/o range, and 29 (6.6%) were older (27 y/o: $n = 4$; 28 y/o: $n = 6$; 29 y/o: $n = 4$; 30 y/o: $n = 1$; 31 y/o: $n = 3$; 32 y/o: $n = 1$; 33 y/o: $n = 2$; 34 y/o: $n = 2$; 35 y/o: $n = 1$; 37 y/o: $n = 2$; 41 y/o: $n = 1$; 43 y/o: $n = 1$; 47 y/o: $n = 1$). The distribution of the responses to Q2–23 is summarized in Figure 1 and Supplementary Figure S2. The female gender was predominant (268 F vs. 161 M; 62.5% F vs. 37.5% M; Supplementary Figure S2A), reflecting not only the gender distribution of the students enrolled at the University of Catanzaro Magna Graecia,

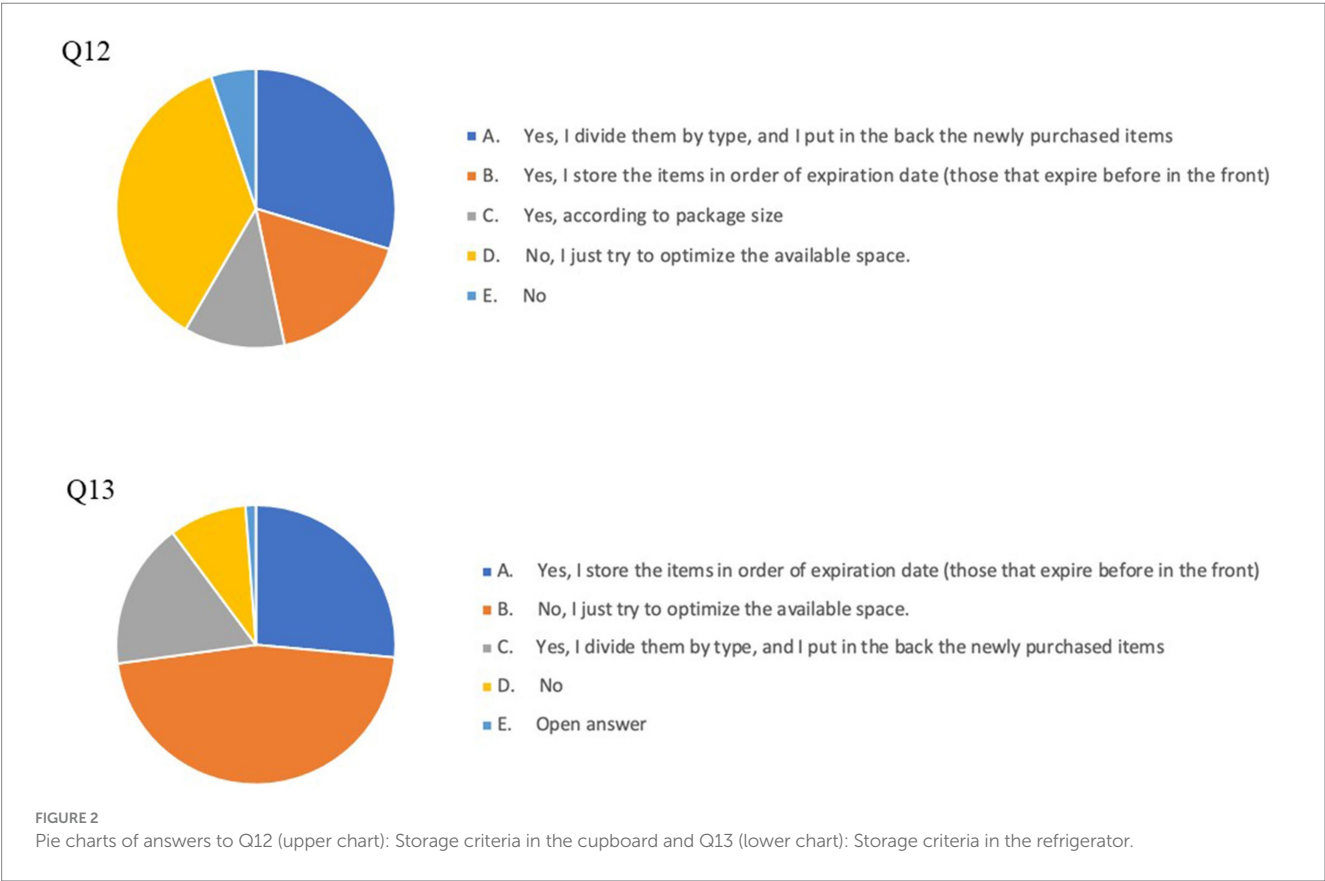
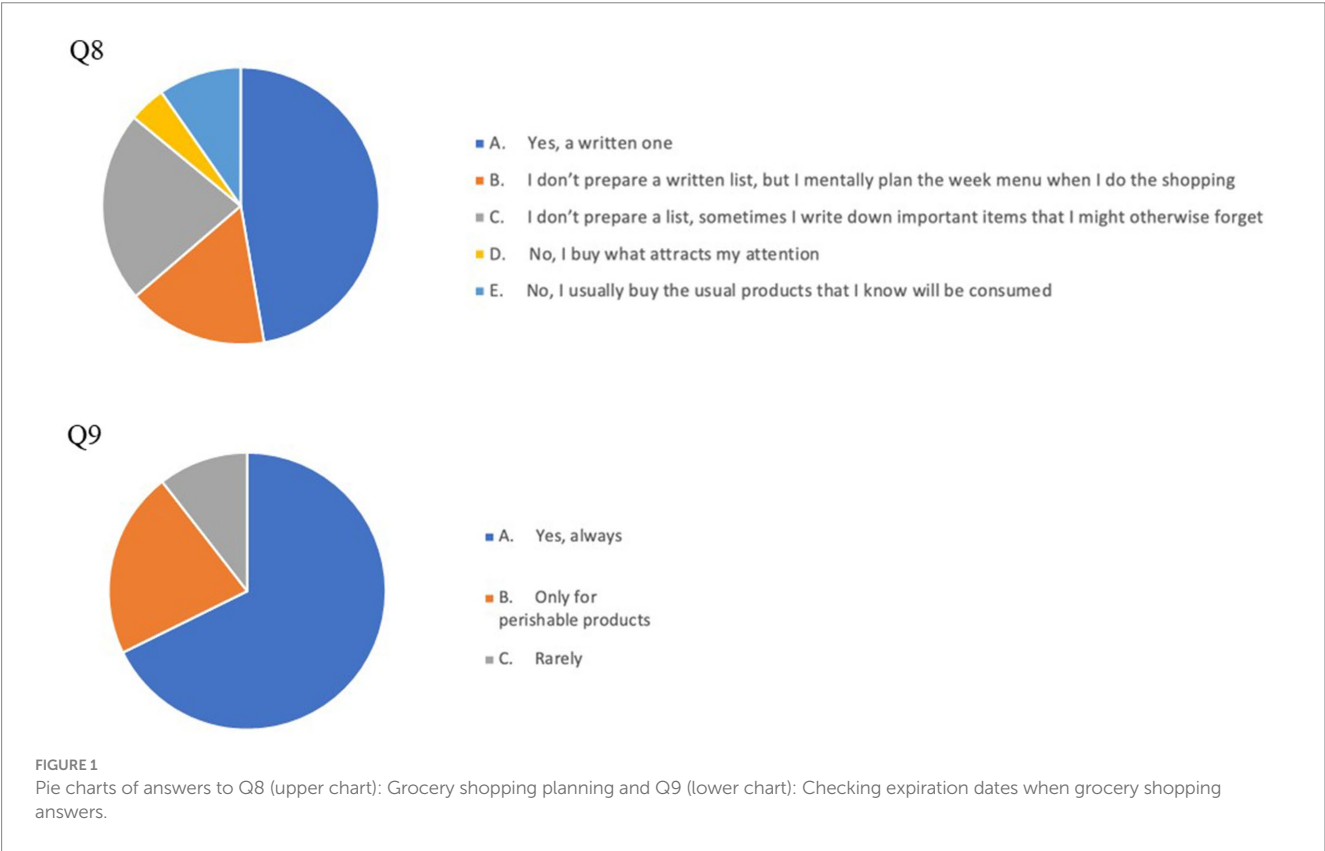
but also the higher willingness of girls and women to respond to surveys, observed across studies (15, 20, 21). The majority of the respondents still lived at home with their parents/family of origin ($n = 255$; 59.2%), 34 (7.9%) lived alone or with a partner with or without children; 142 (33%) lived with roommates; there were no students living in residence halls or other residential communities (Supplementary Figure S2B); 63.1% ($n = 272$) of the entire group personally shopped for groceries (Supplementary Figure S2B), and 91.3% ($n = 394$) was, at least occasionally, involved in meal preparation (Supplementary Figure S2C).

Notably, the vast majority of the whole sample (93.3%, $n = 401$) reported following local separate waste collection rules; even if this response is probably influenced by a social desirability bias, this observation is in keeping with the data on waste disposal in the Catanzaro urban area (Supplementary Figure S2D) (22). It is also worth noting that 61.5% ($n = 260$) of the respondents reported disposing mainly of metal/plastic waste, while the least common response to the question about the type of waste produced in greater amounts was glass ($n = 3$, 0.7%). In addition, “vegetables and fruits gone bad” was the most common response to Q23 ($n = 112$; 26.1%) followed by “meal leftovers” ($n = 77$; 17.9%), and “expired products, not consumed” ($n = 74$; 17.2%; Supplementary Figure S2E).

When we performed a formal statistical analysis on the retained cohort ($n = 346$) obtained after omitting the respondent who did not correctly follow the survey instructions, as detailed in paragraph 2.2, we found significant differences for section B questions (Q5–7) with female students more frequently taking care of food storage and cooking; students enrolled in biomedical area programs more frequently in charge of grocery shopping and cooking; and students living in a new household as well as those living in a non-family household more frequently involved in all three activities (grocery shopping/food storage/cooking). Across the entire sample, 69.9 and 65.6%, respectively, of the respondents who did their own grocery shopping at least once a month took care of food storage at least in part and of cooking their meals, and 62.9% of those who took care of food storage were also responsible for meal preparation. In addition, we observed that male students more frequently did their shopping with a written list, while female students more frequently stored the food items in the refrigerator according to waste-reducing criteria and were less likely to throw away vegetables and fruits when they are no longer fresh. These differences were, however, no longer significant when we matched M/F groups for the number of individuals and section B responses (Tables 1–3).

In addition, respondents living in a family type household as compared with students living in a different type of household as well as students living with their family of origin (old living situation) as compared with students living in a novel household more frequently consumed meals leftover at later meals. However, they also reported slightly more frequently being unable to avoid them; this results in a significant difference in the type of FW, with meal leftovers being the most frequent in these two groups of individuals. All these differences were no longer significant when we matched family/other living situations and new/old living situations groups for group size and Section B responses (Table 4).

In addition, while 97.6% of the respondents affirmed knowing the difference between “use by” and “best before” labeling (66.7% “Yes for sure,” 30.9% “Yes, I think so”; Supplementary Figure S3A); 27.8 and 13.4%, respectively, gave incorrect answers when asked how they



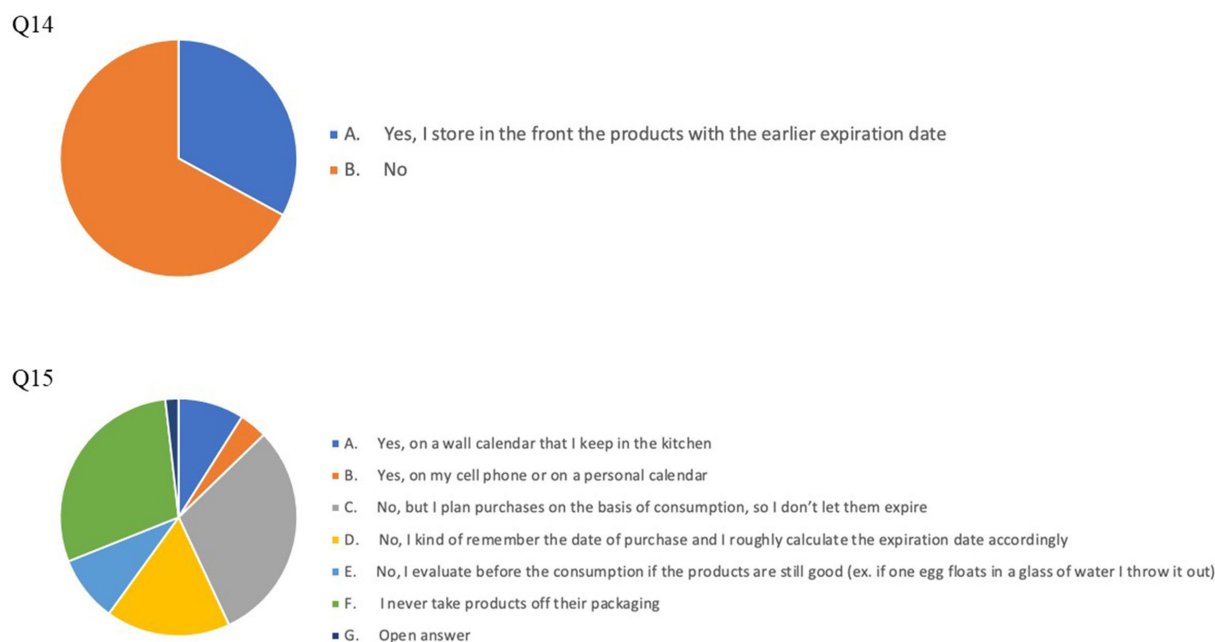


FIGURE 3

Pie charts of answers to Q14 (upper chart): Storage criteria in the freezer and Q15 (lower chart): Expiration date recording.

handled expired products in the two categories (Q18 and Q19, [Supplementary Figure S3B](#)). Interestingly, students enrolled in a program comprising at least one nutrition course gave the correct answers to Q18 significantly more frequently. This difference remained significant after matching the groups for group size and gender and also when the analysis was restricted to students enrolled in programs in the biomedical area and further matched for group size and gender ([Table 5](#)).

There were no significant differences in age distribution in any of the direct comparisons; however, we repeated the analyses after excluding 29 individuals who were older than 26 years and could, thus, be identified as statistical outliers. The results were overall confirmed, with marginal changes in the χ^2 and p values ([Tables 1–5](#) and [Supplementary Tables S1, S2](#)).

In addition, in this cohort, there was a significant difference for Q21. Specifically, families seem to produce a larger amount of undifferentiated and organic waste, while respondents living in non-family households produced larger amounts of plastic and metal waste ([Supplementary Table S2](#)).

Finally, to better understand the factors influencing FW-related behaviors, we generated an arbitrary score, assigning from 0 to 3 points for responses to questions Q8–19, as summarized in [Supplementary Table S3](#). Score values were significantly higher for female students ($p < 0.001$ by Student's t -test). In addition, students living in a non-family-type household as well as students living in a new household showed higher score values as compared, respectively, with those living with their families and with those living in an old household situation ($p < 0.001$ by Student's t -test). The only factors significantly associated with score values in a linear regression analysis were gender and grocery shopping habits. The two factors showed moderate collinearity (VIF: 1.01–1.00); we therefore performed a multiple regression analysis and observed that grocery shopping

habits were the most relevant factor, explaining 45% of the score variance, with gender adding a further 2.6%.

4 Discussion

In this preliminary, descriptive study, we investigated FW-related habits of students enrolled at the University of Catanzaro Magna Graecia in Calabria, a Southern Italian region. Overall, the results of our survey show a high prevalence of virtuous behaviors in the food purchasing phase, with almost 90% of the entire group regularly checking for expiration dates, at least when buying perishable food items, and ~70% of them following a written or mental list/menu, when grocery shopping. In contrast, at home, less than 50% of respondents apply easy-to-implement waste prevention rules, such as storing purchased food according to its expiration date or recording expiration date when removing items from their original packaging. Misplanned food purchases and inadequate food storage have been described as key determinants of FW ([23](#)); however, in our cohort, we were unable to observe significant differences in typology (Q23) or frequency (Q22) of FW according to these characteristics. It is worth noting that, since several studies have demonstrated that consumers are unable to correctly estimate the amount of waste produced in their household, especially when filling out online questionnaires ([23–26](#)) we did not include quantitative questions in our survey. Qualitatively, the most common type of FW was spoiled fruits and vegetables, which is consistent with previous literature data ([10, 23, 24, 27](#)). Meal leftovers and expired, unused products shared the second position, while, contrary to previous reports ([10, 25, 27–29](#)) stale bread was the most frequent food discarded by a comparatively low percentage (7.2%) of respondents. This is all the more remarkable, given that, in our survey, bread and fruits/vegetables were the only categories

TABLE 1 Results of χ^2 analysis for Q5, Q6 and Q7.

Q5. Grocery shopping	A (Always)	B (Usually)	C (Sometimes)	D (Rarely)	E (Never)	χ^2	p
Biomedical/other area	Obs:133/5 Exp:128.43/9.57	Obs:101/5 Exp:98.65/7.35	Obs:59/8 Exp:62.35/4.65	Obs:19/6 Exp:23.27/1.73	Obs:10/0 Exp:9.31/0.69	17.8	0.001
Biomedical/other area no outliers	Obs:122/5 Exp:117.87/9.13	Obs:93/5 Exp:90.96/7.04	Obs:53/7 Exp:55.69/4.31	Obs:19/6 Exp:23.20/1.80	Obs:10/0 Exp:9.28/0.72	15.8	0.003
Family/ other living situation	Obs:23/115 Exp:77/61	Obs:73/33 Exp:59.1/46.9	Obs:63/4 Exp:37.4/29.6	Obs:24/1 Exp:13.9/11.1	Obs:10/0 Exp:5.58/4.42	157	<0.001
Family/other living situation no outliers	Obs:20/107 Exp:70.6/56.4	Obs:67/31 Exp:54.5/43.5	Obs:57/3 Exp:33.4/26.6	Obs:24/1 Exp:13.9/11.1	Obs:10/0 Exp:5.56/4.44	150	<0.001
New/old living situations	Obs:119/19 Exp: 65.8/72.2	Obs:36/70 Exp: 50.5/55.5	Obs:36/70 Exp: 50.5/55.5	Obs:36/70 Exp:50.5/55.5	Obs:0/10 Exp:4.77/5.23	150	<0.001
New/old living situations no outliers	Obs:108/19 Exp:58.7/68.3	Obs:31/57 Exp:45.3/52.7	Obs:8/52 Exp:27.8/32.3	Obs:1/24 Exp:11.6/13.4	Obs:0/10 Exp:4.63/5.38	138	<0.001
Q6. Food storage	A (Always)	B (Usually)	C (Partly)	D (Never)	E (never Q5 and Q6)	χ^2	p
M/F	Obs:57/128 Exp:62.9/122.1	Obs:47/91 Exp:46.9/91.1	Obs:5/2 Exp:2.38/4.62	Obs:3/4 Exp:2.38/4.62	Obs:5/2 Exp:2.38/4.62	9.82	0.044
M/F no outliers	Obs:53/116 Exp:58.3/110.7	Obs:44/86 Exp:44.8/85.2	Obs:5/2 Exp:2.41/4.59	Obs:3/3 Exp:2.07/3.93	Obs:5/2 Exp:2.41/4.59	9.85	0.043
Family/other living situation	Obs:69/116 Exp:103.2/81.8	Obs:103/37 Exp:78.1/61.9	Obs:7/0 Exp:3.90/3.10	Obs:7/0 Exp:3.90/3.10	Obs:7/0 Exp:3.90/3.10	60.2	<0.001
Family/other living situation no outliers	Obs:64/105 Exp:94/75	Obs:94/37 Exp:72.9/58.1	Obs:7/0 Exp:3.89/3.11	Obs:6/0 Exp:3.34/2.66	Obs:7/0 Exp:3.89/3.11	51.3	<0.001
New/old living situations	Obs:124/61 Exp:88.2/96.8	Obs:40/100 Exp:66.8/73.2	Obs:0/7 Exp:3.34/3.66	Obs:1/6 Exp:3.34/3.66	Obs:0/7 Exp:3.34/3.66	64.1	<0.001
New/old living situations no outliers	Obs:109/60 Exp:78.2/90.8	Obs:39/92 Exp:60.6/70.4	Obs:0/7 Exp:3.24/3.76	Obs:0/6 Exp:2.77/3.23	Obs:0/7 Exp:3.24/3.76	54.2	<0.001
Q7. Cooking	A (Yes, for self)	B (yes for household)	C (Sometimes)	D (Never)	E (Rarely)	χ^2	p
M/F	Obs:39/62 Exp:34.4/66.6	Obs:21/76 Exp:33/64	Obs:40/75 Exp:39.1/75.9	Obs:8/5 Exp:4.42/8.58	Obs:7/6 Exp:4.42/8.58	19.7	0.020
M/F no outliers	Obs:35/59 Exp:32.4/61.6	Obs:19/68 Exp:30/57	Obs:41/70 Exp:38.3/72.7	Obs:8/5 Exp:4.48/8.52	Obs:7/7 Exp:4.83/9.17	12.5	0.014
Biomedical/other area	Obs:99/2 Exp:93.99/7.01	Obs:85/12 Exp:90.27/6.73	Obs:113/7 Exp:111.68/8.32	Obs:14/0 Exp:13.03/0.97	Obs:11/3 Exp:13.03/0.97	14.1	0.007
Biomedical/other area no outliers	Obs:92/2 Exp:87.24/6.76	Obs:75/12 Exp:80.75/6.25	Obs:105/6 Exp:103.02/7.98	Obs:14/0 Exp:12.99/1.01	Obs:11/3 Exp:12.99/1.01	15.2	0.004
Family/other living situation	Obs:25/76 Exp:56.3/44.7	Obs:57/40 Exp:54.1/42.9	Obs:84/36 Exp:66.9/53.1	Obs:14/0 Exp:7.81/6.19	Obs:13/1 Exp:7.81/6.19	68.8	<0.001
Family/other living situation no outliers	Obs:23/71 Exp:52.3/41.7	Obs:50/37 Exp:48.4/38.6	Obs:78/33 Exp:61.7/49.3	Obs:14/0 Exp:7.79/6.21	Obs:13/1 Exp:7.79/6.21	65.8	<0.001
New/old living situations	Obs:77/24 Exp:48.2/52.8	Obs:47/50 Exp:46.7/50.7	Obs:39/77 Exp:55.3/60.7	Obs:0/14 Exp:6.68/7.32	Obs:0/13 Exp:6.20/6.80	71.8	<0.001
New/old living situations no outliers	Obs:72/22 Exp:43.5/50.5	Obs:40/47 Exp:40.2/46.8	Obs:35/76 Exp:51.3/59.7	Obs:0/14 Exp:6.47/7.53	Obs:1/13 Exp:6.47/7.53	65.2	<0.001

Obs, observed; Exp, expected; M, male; F, female; χ^2 , chi-square; p , p -value.

TABLE 2 Results of χ^2 analysis for Q8.

Q8. Grocery shopping planning	A (Yes, written)	B (Weekly menu)	C (Note important items)	D (Impulsive shopping)	E (Routinary shopping)	χ^2	p
M/F	Obs:47/97 Exp:44.7/99.3	Obs:18/29 Exp:14.6/32.4	Obs:12/56 Exp:21.1/46.9	Obs:3/7 Exp:3.10/6.90	Obs:10/11 Exp:6.52/14.48	9.73	0.045
M/F no outliers	Obs:44/85 Exp:40.74/88.26	Obs:16/27 Exp:13.58/29.42	Obs:11/54 Exp:20.53/44.47	Obs:3/5 Exp:2.53/5.47	Obs:10/11 Exp:6.63/14.37	10.11	0.039

Obs, observed; Exp, expected; M, male; F, female; χ^2 , chi-square; p , p -value.

TABLE 3 Results of χ^2 analysis for Q13.

Q13. Storage criteria in the refrigerator	A (Expiration date)	B (Space optimization)	C (Type)	D (None)	χ^2	p
M/F	Obs:27/61 Exp:27.8/60.2	Obs:54/91 Exp:45.9/99.1	Obs:9/47 Exp:17.7/38.3	Obs:10/17 Exp:8.54/18.46	8.78	0.032
M/F no outliers	Obs:24/56 Exp:25.5/54.5	Obs:52/79 Exp:41.7/89.3	Obs:8/47 Exp:17.5/37.5	Obs:9/17 Exp:8.28/17.72	11.5	0.009

Obs, observed; Exp, expected; M, male; F, female; χ^2 , chi-square; p , p -value.

TABLE 4 Results of χ^2 analysis for Q16 and Q17.

Q16. Fruits and vegetable no longer fresh	A (Throw them away)	B (Save good parts)	C (Cook them)	χ^2	p
M/F	Obs: 25/31 Exp: 17.6/38.4	Obs: 66/161 Exp: 71.5/115	Obs:7/21 Exp:8.82/19.18	5.65	0.050
M/F no outliers	Obs:24/28 Exp:16.67/35.33	Obs:62/148 Exp:67.32/142.68	Obs:6/19 Exp:8.01/16.99	6.11	0.047
Family/ other living situation	Obs:20/36 Exp:28.90/27.10	Obs:128/100 Exp:117.65/110.35	Obs:13/15 Exp:14.45/13.55	7.84	0.020
Family/other living situation no outliers	Obs:17/35 Exp:26.63/25.37	Obs:118/92 Exp:107.56/102.44	Obs:12/13 Exp:12.80/12.20	9.32	0.009
New/old living situations	Obs:38/18 Exp:29.26/26.74	Obs:109/119 Exp:119.12/108.88	Obs:16/12 Exp:14.63/13.37	7.54	0.023
New/old living situations no outliers	Obs:36/16 Exp:26.45/25.55	Obs:97/113 Exp:106.83/103.17	Obs:13/12 Exp:12.72/12.28	8.87	0.012
Q17. Meal leftovers	A (Throw them away)	B (Consume later)	C (No leftovers)	χ^2	p
Family/other living situation	Obs:11/10 Exp:10.83/10.17	Obs:90/62 Exp:78.42/73.58	Obs:61/80 Exp:72.75/68.25	7.45	0.024
Family/other living situation no outliers	Obs:7/10 Exp:8.71/8.29	Obs:85/58 Exp:73.2/69.8	Obs:56/73 Exp:66.1/62.9	7.70	0.021
Family/other living situation matched for age and gender	Obs:8/9 Exp:7.61/9.39	Obs:58/48 Exp:47.5/58.5	Obs:37/70 Exp:47.9/59.1	8.77	0.012
New/old living situations	Obs:12/9 Exp:10.97/10.03	Obs:67/85 Exp:79.39/72.61	Obs:85/56 Exp:73.64/67.36	7.92	0.019
New/old living situations no outliers	Obs:10/7 Exp:8.65/8.35	Obs:62/81 Exp:72.74/70.26	Obs:75/54 Exp:65.62/63.38	6.39	0.041

Obs, observed; Exp, expected; M, male; F, female; χ^2 , chi-square; p , p -value.

specifically mentioned as FW typology, while all other food items were grouped into the two main categories of “meal leftovers” and “expired unused products”; thus, it would have been possible to anticipate a higher number of respondents choosing “bread” as an answer. It may

be possible to hypothesize that the symbolic religious value of bread is still stronger in the Calabrian region (30) than in less traditionally oriented regions, even if the cohort recently analyzed by Fanelli et al. (28) as well as the students interviewed by Mondéjar-Jiménez (10)

TABLE 5 Results of χ^2 analysis for Q18.

Q18. Expired "use by" products	A (Taste and use)	B (Use good parts)	C (Throw away)	D (Cook, with caution)	E (rarely happens)	χ^2	<i>p</i>
Nutrition course(s)/ no nutrition course	Obs:23/46 Exp:27.9/41.1	Obs:6/9 Exp:6.07/8.93	Obs:76/72 Exp:59.9/88.1	Obs: 0/3 Exp:1.25/1.75	Obs:22/57 Exp: 32/47	16	0.003
Nutrition course(s)/ no nutrition course no outliers	Obs:23/40 Exp:26.16/36.84	Obs:4/8 Exp:4.98/7.02	Obs:73/85 Exp:57.3/80.7	Obs:0/3 Exp:1.25/1.75	Obs:20/53 Exp:30.31/42.69	16.47	0.002
Nutrition course(s)/ no nutrition courses matched for gender	Obs:23/21 Exp:25.9/18.1	Obs:6/1 Exp:4.12/2.88	Obs:76/37 Exp:66.4/46.6	Obs:0/1 Exp:0.59/0.41	Obs:22/29 Exp:30/21	12.8	0.012
Nutrition course(s)/ no nutrition course (biomedical area cohort)	Obs:23/38 Exp:26.4/34.6	Obs:6/8 Exp:6.07/7.93	Obs:76/64 Exp:60.7/79.3	Obs: 0/2 Exp:0.86/1.13	Obs:22/54 Exp:32.9/43.1	15.6	0.004
Nutrition course(s)/ no nutrition course (biomedical area cohort) matched for gender	Obs: 23/24 Exp:23/24	Obs:6/4 Exp: 4.9/5.1	Obs:76/56 Exp: 64.7/67.3	Obs:0/2 Exp:0.98/1.02	Obs:22/46 Exp: 33.3/34.7	13.8	0.008

Obs, observed; Exp, expected; χ^2 , chi-square; *p*, *p*-value.

lived in Southern and Central Italian Regions that share a similar cultural heritage with Calabria.

Interestingly, more than 90% of the whole cohort declared following the rules for separate waste collection, and only 2.3% stated that a collection system has not been implemented in their area of residence. The presence of an organized and efficient separate waste collection organization has been suggested to be associated with a reduction of FW, as it likely increases environmental sensitivity and heightens the care devoted to waste disposal (13, 24). As far as waste typology is concerned, the prevalence of respondents who indicated "plastic and metal" as the most common waste appears also noteworthy. Single-use packaging is, by far, the major application of plastic in Europe (40%) (31) and, even if feasible, at home reusing of plastic containers (such as plastic bottles refilled with other beverages, especially hot ones) is not recommended as it has been demonstrated that reused plastic releases an increased amount of ftalates (32). The burden of reducing plastic waste thus lays on producers rather than consumers, but it has been proposed that the two issues would benefit from being addressed together as there are significant overlaps in possible optimizing strategies (33).

In addition, we observed several significant differences when comparing subgroups based on established or putative determinants of FW behaviors (gender, housing situation, degree program); however, none of these differences survived matching for group size and relevant habits (Section B questions). The only exception was the more appropriate handling of "use by" products by respondents who received structured nutrition teaching. We believe that this observation reinforces the importance of adequate education in the nutrition field (34).

Overall, direct involvement in grocery shopping appears to be the major determinant of our arbitrarily generated food wasting score. This observation is contrary to previous data suggesting that younger

consumers have a lower ability to manage household food consumption (35); it could, however, be interpreted as a sign of the increasing attention toward environmental issues in the younger generations, who, when living independently, may choose to adopt more virtuous behaviors than those of their family of origins.

Interestingly, the only other variable giving a contribution, albeit minimal, to explain the score was gender. Gender has, indeed, been previously shown to influence FW related behavior. Women have been reported to have better knowledge of leftover processing and, particularly mothers of young children, tend to consume meal leftovers themselves rather than throwing them away (36, 37). However, they may also be more inclined than men to discard leftovers in their attempt to provide healthy and fresh meals to their family (38) and a decade-old Finnish study surprisingly shows increased FW rates in households where a woman was primarily in charge of grocery shopping (39). Also, girls seem to waste more food than boys in the school lunchrooms, and this appears to be due to their desire to eat healthier food (16). The challenges associated with conjugating high nutritional quality with low environmental impact have been highlighted also by a recent study in a French student cohort, where the Authors observed that independently living students tend to be more environmentally aware, in keeping with our observations, while students living with their family of origin followed a healthier diet. Interestingly, they did not observe any gender-related association; this may be partly explained by the socio-cultural differences between French and Italy (17). Indeed, unadjusted comparisons between the two genders show that women in our cohort are more frequently in charge of menial tasks, such as storing food items or cooking for the whole household, while males more frequently cook special meals. These observations highlight the need to better understand the drivers of FW and

further underline the importance of an adequate education in the nutrition field, encompassing different aspects from health eating to FW reduction.

Our choice to carry out the survey by online questionnaires has pros and cons. First of all, the participation was voluntary; this may result, as previously shown, in a selection bias toward more aware and interested individuals; however, students were invited to participate during regular frontal lessons on subjects related as well as unrelated to nutrition issues and did not know the survey content in advance. The choice to omit from the formal analysis the respondents who did not correctly follow the survey instructions was, in fact, aimed at obtaining more robust results, since it can be hypothesized that these respondents had not paid enough attention while filling out the online form. It has also been observed that online anonymous questionnaires reduce the social desirability bias; to this end, we also employed a neutral tone and supplied “face-saving” alternatives whenever appropriate to encourage honest answers (40).

As noted above, quantitative data have not been included in our questionnaire, as it has been demonstrated that they cannot be reliably obtained through online forms (24, 25, 41). We also favored short straightforward questions to increase the number of respondents filling out the whole questionnaire; we were therefore unable to gather information on a number of factors which have been suggested, in previous studies, to affect FW related behaviors, including preferred shopping venues (supermarkets vs. local stores etc.), number and age of individuals sharing the same household, household income, frequency of not eating at home. The low mean age of our cohorts makes possible to infer that respondents living with their own new family will have young children, and the number of individuals under the age of 18 in a household has been reported to be associated either with a higher (42) or with a lower (27) rate of FW; however, the number of students ($n=13$) living with their new families was too low to allow detecting any significant difference. By contrast, it has been suggested that individuals older than 65 have a greater awareness toward FW (21, 43) even if some studies do not confirm this observation (25, 44), parents of university age individuals, as those enrolled in our study, belong, likely, to a lower age range; thus, obtaining information on the household composition, including the presence of grandparents and older adults, could probably have helped to address this aspect. We also did not ask information on household income, which has been shown to represent a key determinant of FW (29); nonetheless, we hypothesize that the highest score of respondents living in a new housing situation as compared to those living with their family of origins may likely be in part determined by the lower economic possibility of younger families and students living on their own.

In conclusion, our results highlight the potential benefits of extending nutrition education to all university programs to allow young adults to acquire appropriate knowledge, which may help them in their quest to reduce FW preserving at the same time their health as well as the health of the planet (34).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The requirement of ethical approval was waived by Comitato Etico Azienda Ospedaliera “Mater Domini” for the studies involving humans because answers were anonymous and non-sensitive data only were collected. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

FC: Formal analysis, Investigation, Writing – original draft, Writing – review & editing. VC: Investigation, Writing – original draft. AP: Conceptualization, Writing – review & editing. AS: Writing – review & editing. MH: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2024.1401581/full#supplementary-material>

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Contribution of fish to food and nutrition security in Southern Africa: challenges and opportunities in fish production

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This study investigated the role of fish in addressing food and nutrition security challenges in Southern Africa, focusing on 10 countries including Angola, Zambia, Malawi, Mozambique, Namibia, Botswana, Zimbabwe, Lesotho, Eswatini, and South Africa. It examined the current state of food and nutrition security, fish production, and fish consumption patterns. Additionally, the study investigated the challenges and opportunities to enhance fish production in these countries thereby enhancing food and nutrition security. The findings revealed persistent challenges such as a high prevalence of food insecurity and malnutrition throughout the region. Fish production is hindered by overexploitation of fishery resources, inadequate fisheries management, susceptibility to climate-related shocks, limited investments in aquaculture, and inadequate access to input supplies such as quality fish seed

and feed. Despite these obstacles, opportunities exist to promote sustainable fish production to enhance food security and nutrition. Countries endowed with extensive coastlines and inland waters exhibit significant potential for fishery development, while landlocked nations are increasingly exploring aquaculture as a viable solution. Addressing the challenges in fish production and capitalizing on opportunities requires comprehensive governance, technological innovation, policy interventions, and investment to ensure the sustainability and resilience of the fisheries and aquaculture industries in the region.

KEYWORDS

aquaculture, blue foods, fisheries, nutrition, fish, sub-Saharan Africa

1 Introduction

Hunger and malnutrition are significant challenges that impact a substantial part of the global population. In 2020, about 3.1 billion people were unable to afford a healthy diet, while 2.3 billion people were considered to have moderate or severe food insecurity in 2021 (1). These challenges are exacerbated by climate risks, the contraction of global economies, conflicts, and a rapidly growing human population, making the agri-food system extremely vulnerable to shocks and disruptions (2). About a third (2.4 billion people) of the global population, of which majority are women and people living in rural areas, have no access to nutritious, safe, and sufficient food all year round (2). Due to unequal distribution of food, stunting, wasting, and overweight continue to severely affect millions of people, making it impossible for the world to meet the 2030 targets of ending hunger, food insecurity, and malnutrition in all forms (2). Additionally, the increasingly negative impact of micronutrient deficiency on the global population highlights the urgent need to transform existent food policies and focus on not only the quantity but also the quality of the food consumed (3, 88, 89).

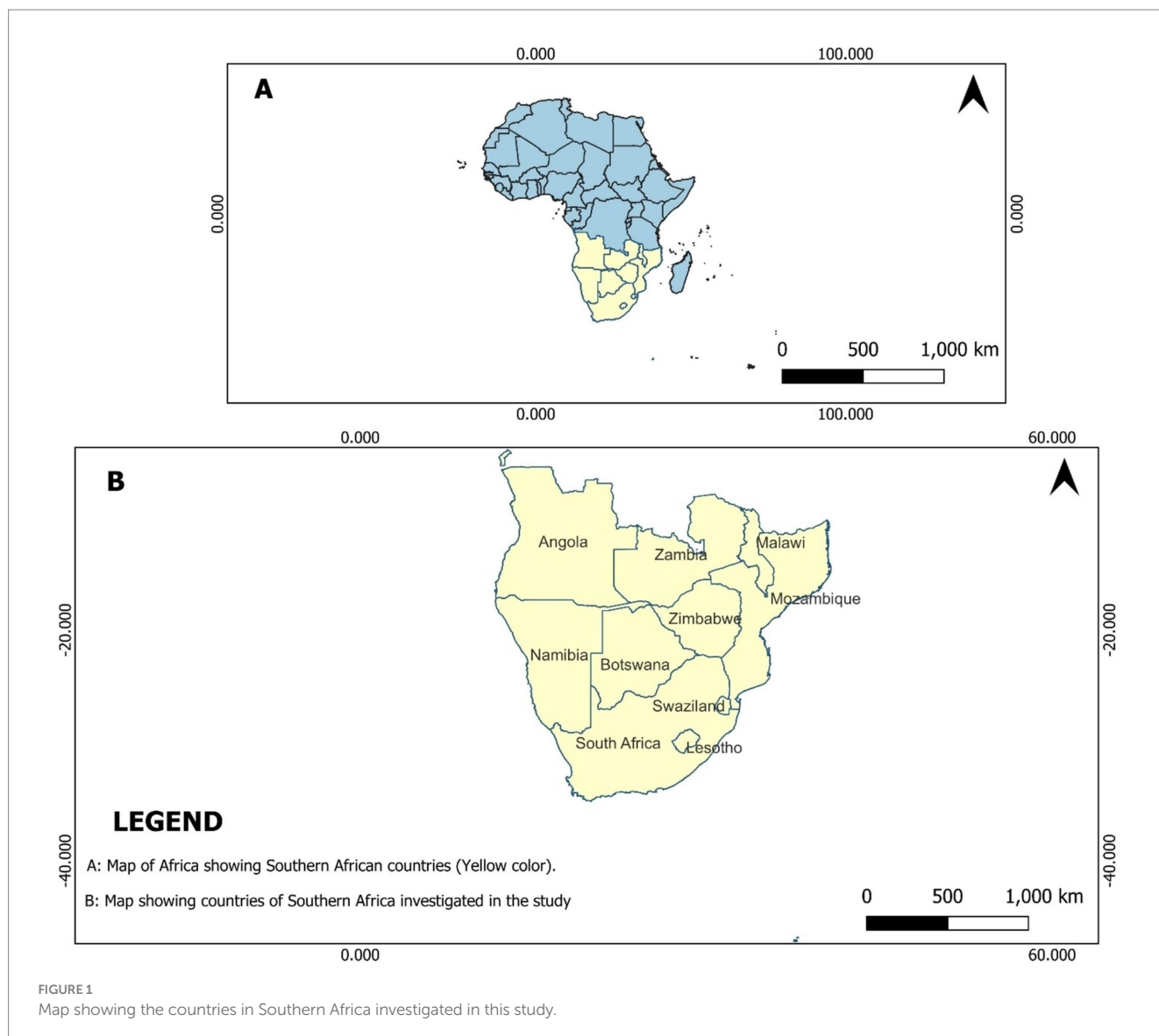
At the same time, the global population is expanding rapidly with Africa projected to account for most of the population growth by 2050 (4). The sub-Saharan Africa (SSA) in particular, has continued to record the fastest-growing population since the 1980s (5). On the other hand, the prevalence of undernourishment remains high in Africa with the sub-Saharan region being the most affected (2). For instance, in 2020, SSA experienced the highest prevalence of undernourishment globally, with 264.2 million people affected, accounting for approximately 24.1% of the population (6, 7). Moreover, affordability for healthy diets is particularly low in sub-Saharan Africa, where an estimated 875 million people cannot afford the cost of a nutritious diet [(8, 93)]. Furthermore, the increase in the prevalence of food insecurity reached the highest in this region in 2022, while micronutrient deficiency, also known as hidden hunger, also continues to persist, affecting three-quarters of the African population (2). Therefore, it is becoming increasingly evident that traditional food production and consumption patterns are inadequate, or the nutritional value of such foods is deficient to support and nourish the projected increase in the regional population. Addressing these challenges effectively requires coordinated efforts at local, national, and international levels to ensure access to nutritious food, improve food security, and promote sustainable food systems.

Fish play a key role in the global food supply, accounting for around 17% of dietary animal protein intake, and reaching more than 50% in some countries in Asia and Africa (9). They often represent a highly affordable, easily available, and accessible source of animal protein and micronutrients that play a crucial role in food and nutrition, as well as in the income security of many people (9, 12, 90). Fish have been recognized as an important food item for providing the proteins required for human nutrition (13, 14). It is a rich source of proteins and essential fatty acids besides numerous bioavailable micronutrients required to overcome nutritional deficiency in children, expectant mothers, and adults. Expanding fish production through sustainable aquaculture and fisheries development could potentially play a significant role in improving food and nutrition security in Africa.

Despite the increasingly important role of aquatic foods in food and nutrition security, Africa's production has remained relatively low at 7% of global production (9). Additionally, the *per capita* consumption of fish in Africa, particularly in SSA, is expected to decrease due to insufficient supply growth to match the pace of population expansion (9). Curbing the challenges of food and nutrition insecurity in the region will require increased production and consumption of nutritious foods such as fish. Regrettably, the role of fish in food and nutrition security has received less attention in Africa, which may be one of the major reasons for the consistently low fish production in this region (9). This study aimed to investigate the contribution of fish to food and nutrition security in Southern Africa. This study further explored the challenges and opportunities for increasing fish production in this region.

2 Methods

Ten Southern African countries belonging to the Southern African Development Community (SADC) were selected for investigation in this study (Figure 1). These countries were selected based on both their geographical characteristics and their involvement in SADC programs designed to promote fish production in the region. The study was conducted through a comprehensive review of the existing literature relating to food and nutrition security, fish consumption, and fish production in Southern African countries. The aim was to compile and analyze data sourced primarily from reputable organizations such as the United Nations Food and Agriculture Organization (FAO), World Bank, and peer-reviewed journals.



To ensure a rigorous and transparent assessment, we assembled expert teams from each country under study, with a focus on individuals with expertise in fisheries, aquaculture, or food security. By involving experts from each country, the study aimed to incorporate local knowledge and perspectives into the study. Following the formation of expert teams, independent reviews of the existing literature were conducted, with one team focusing on literature sources and the other examining FAO databases for food security indicators, nutrition data, fish production, aquatic product trade statistics, and fish consumption specific to each selected country. Upon data collection, careful comparisons were made among the various sources. In instances where minor discrepancies arose, data sourced from the FAO were prioritized to ensure transparency and consistency. Moreover, great care was taken to ensure that data comparisons between countries were based on information from the same sources and timeframes, thus ensuring uniformity in data presentation and interpretation.

Additionally, a thorough review of peer-reviewed scientific papers was conducted to identify and assess the challenges and opportunities in fish production from capture fisheries and aquaculture. This

complementary information, along with the gathered data, formed the basis for a critical analysis of the obstacles facing capture fisheries and aquaculture production in the region. Moreover, it allowed the identification of opportunities aimed at promoting fish production and subsequently enhancing its role in addressing food and nutrition security concerns. This holistic approach facilitated the synthesis of relevant information to provide guidance on policies and strategies for promoting sustainable and resilient fisheries and aquaculture sectors in the region.

3 Results

3.1 Geographic and economic profile of selected countries

Key geographic, hydrological, demographic, and economic indicators for the selected Southern African countries are presented in [Table 1](#). Angola has the largest total area, covering 1,246,700 square kilometers, and possesses substantial inland waters and coastlines.

TABLE 1 Key geographic, hydrological, demographic, and economic indicators of the countries studied.

Country	Total size (Km ²) ¹	Surface area of inland waters ²	Coastline length (km) ³	Total renewable water (billion m ³ /year) ¹	Population (Million, 2021) ⁴	GDP (\$/capita, 2022) ⁵
Angola	1,246,700	2,359	1,600	148.4	34.5	3256.34
Botswana	581,730	642	0	12.2	2.6	7274.23
Eswatini	17,360	70	0	4.5	1.2	4025.32
Lesotho	30,360	70	0	3.0	2.3	1107.40
Malawi	118,480	24,242	0	17.3	19.9	622.48
Mozambique	786,380	14,916	2,470	217.1	32.1	541.45
Namibia	824,290	5,101	1,572	39.9	2.5	4828.45
South Africa	1,219,090	5,509	2,798	51.4	59.4	6776.48
Zambia	752,610	14,042	0	104.8	19.5	1431.86
Zimbabwe	390,760	4,472	0	20.0	16.0	1553.54

¹FAO AQUASTAT main country database (accessed on 15 April 2024).

²FAOSTAT land cover database (updated in 2020; CCL_LC).

³The World Factbook, Central Intelligence Agency (CIA), United States of America (accessed on 18 April 2024).

⁴United Nations, World Population Prospects (4).

⁵Determined by dividing total GDP (IMF World Economic Outlook Database) by population (UN World Population Prospects) in 2022.

Botswana, though landlocked with no coastline, has a considerable surface area of inland waters relative to its total size. Eswatini (formerly Swaziland) and Lesotho have limited inland waters and no coastline, reflecting their small sizes. Malawi has a significant surface area of inland waters compared to its overall size. Mozambique has an extensive coastline and substantial inland waters, aligned with its large total size. Namibia's coastline is prominent, contributing to its relatively small total size; its inland waters are noteworthy. South Africa, with its diverse geography, has an extensive coastline and substantial inland waters. Zambia and Zimbabwe, both landlocked without coastlines, have varying sizes and inland water resources. Regarding population and Gross Domestic Product (GDP) *per capita*, South Africa and Angola lead, whereas Eswatini, Lesotho, and Botswana have smaller populations and relatively higher GDP *per capita*.

3.1.1 Population dynamics

Figure 2 illustrates the changes in total rural and urban populations across the 10 African countries between 2011 and 2021. Angola experienced the most significant overall population growth at 41.98%, coupled with substantial urbanization (54.42%). Botswana and South Africa showed moderate population growth (23.81 and 13.36%, respectively), with notable urbanization trends (38.46 and 22.87%, respectively). Malawi, Mozambique, and Zambia exhibited substantial population increases (31.79, 33.75, and 36.36%, respectively) and noteworthy urbanization rates (54.17, 54.32, and 52.63%, respectively). Lesotho and Eswatini saw moderate population growth (15.00 and 9.09%, respectively) and substantial urbanization (32.69 and 28.57%, respectively). Namibia and Zimbabwe experienced moderate population growth (19.05 and 23.08%, respectively) with varying urbanization rates (59.57 and 23.40%, respectively).

3.2 Status of food and nutrition security

The average prevalence of severe food insecurity and undernourishment in various Southern African countries between

2020 and 2022 is depicted in Figure 3. Malawi had the highest prevalence of severe food insecurity at 52.20%, accompanied by a significant undernourishment rate of 17.8%. Lesotho also faced substantial challenges with 32.80% experiencing severe food insecurity and a high undernourishment rate of 46%. Mozambique, Angola, Zambia, and Zimbabwe exhibited notable levels of both severe food insecurity and undernourishment. Conversely, South Africa showed lower rates, with only 9.00% experiencing severe food insecurity and 7.9% facing undernourishment. Eswatini and Namibia had relatively lower prevalence rates for both indicators. Botswana had a slightly lower rate of undernourishment at 22.9%, despite facing a considerable prevalence of severe food insecurity at 26.70%.

The key nutritional security indicators in various Southern African countries are summarized in Table 2. Stunting in children under 5 years old was most prevalent in Angola, Mozambique, Malawi, and Lesotho, reflecting high levels of chronic malnutrition. Wasting, an acute form of malnutrition, was notably present in Lesotho and Mozambique. Overweight rates among young children were highest in South Africa and Botswana. The adult obesity rates were particularly notable in Angola and South Africa. Anaemia was widespread in women of reproductive age (15–45 years), with Mozambique (47.9%) and Angola (44.5%) showing the highest prevalence.

3.2.1 Cost and affordability of a healthy diet by country in Southern Africa

Table 3 provides information about the affordability and composition of healthy diets across several African countries. This reveals the cost distribution of various food categories that contribute to a balanced diet. Animal sources, vegetables, and fruits are relatively expensive components, particularly in countries such as Angola, Botswana, Eswatini, Lesotho, Malawi, and South Africa, where the cost of a healthy diet based on purchasing power parity (PPP) was relatively high. In contrast, Namibia showed a lower percentage of people unable to afford a healthy diet, while Malawi faced the highest percentage of people unable to afford a healthy diet.

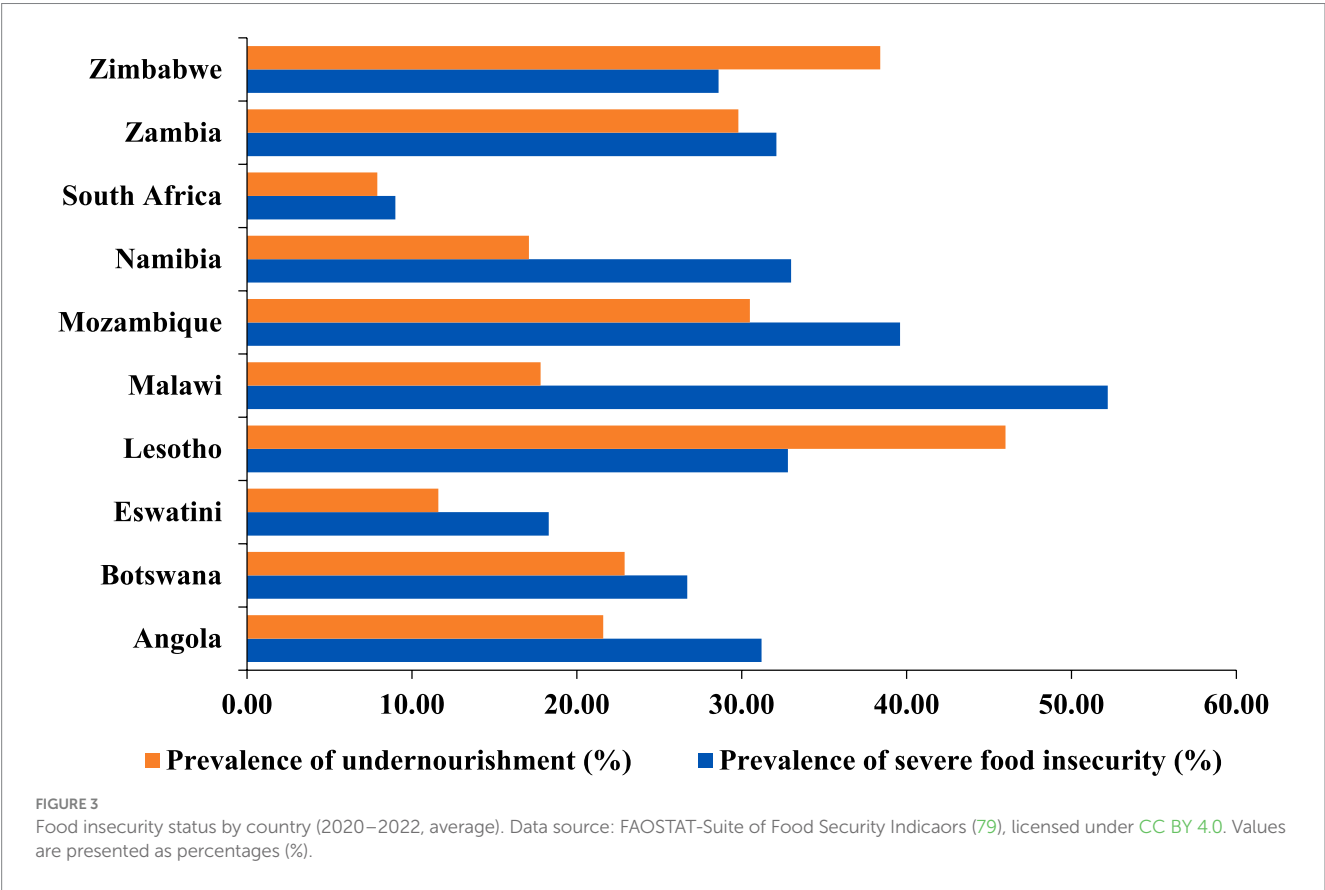
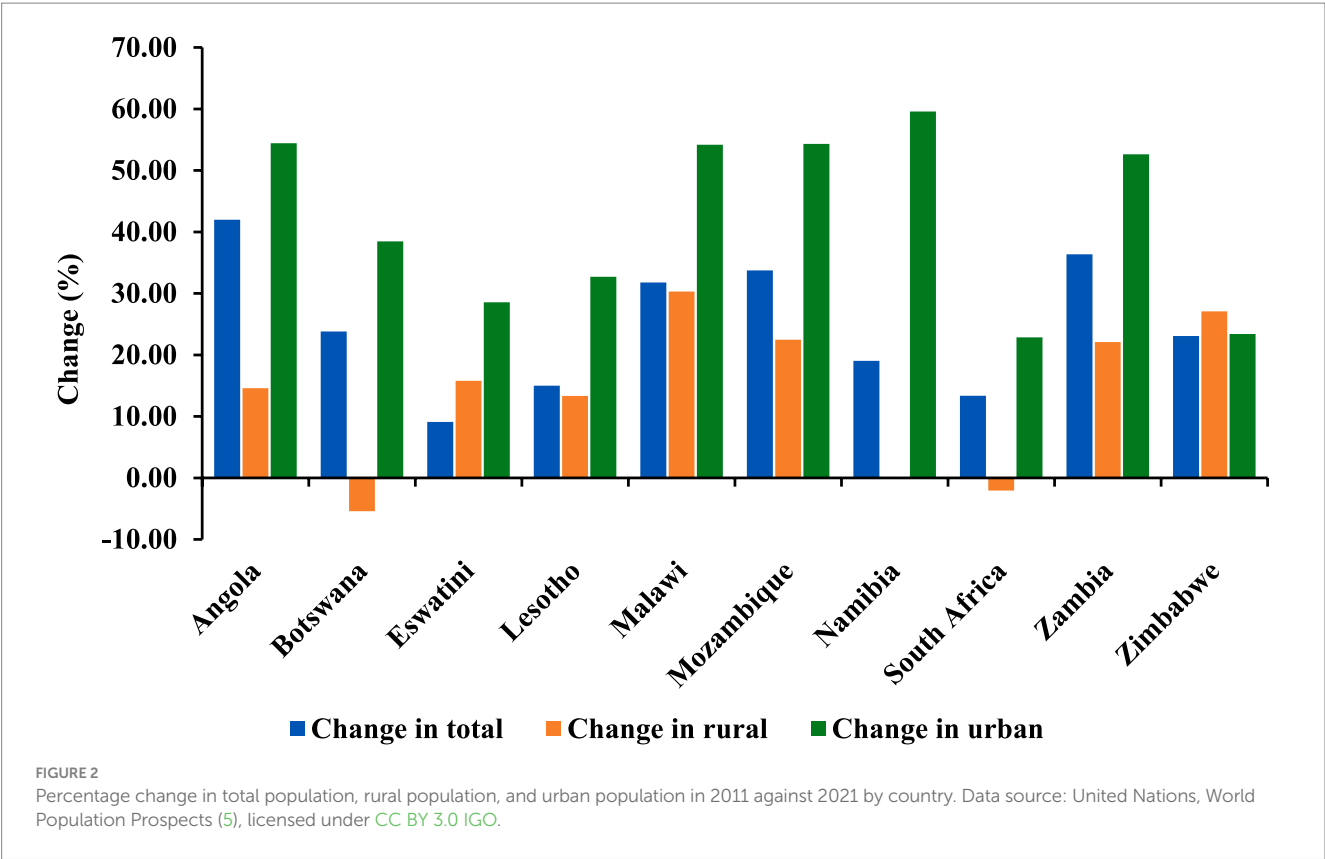


TABLE 2 Nutrition security status by country in Southern Africa.

Country	Stunting in children (<5 yrs.), 2022	Wasting in children (<5 yrs.), 2022	Overweight in children (<5 yrs.), 2022	Obesity in adults (+18 yrs.), 2016	Anaemia in women (15–45 yrs.), 2019
Angola	43.6	-	3.9	8.2	44.5
Botswana	21.6	-	10.1	18.9	32.5
Eswatini	21.2	-	7.9	16.5	30.7
Lesotho	31.8	2.1	6.9	16.6	27.9
Malawi	34.0	2.6	3.9	5.8	31.4
Mozambique	36.4	3.9	5.5	7.2	47.9
Namibia	16.8	-	5.3	17.2	25.2
South Africa	22.8	3.8	12.1	28.3	30.5
Zambia	31.4	4.2	5.4	8.1	31.5
Zimbabwe	21.6	2.9	2.7	15.5	28.9

Data source: FAOSTAT—suite of food security indicators (79).

TABLE 3 The estimated cost of a healthy diet (PPP dollar/person/day) in 2017.

Country	Animal source	Starchy staples	Legumes, nuts, and seeds	Vegetables and fruits	Fruits	Oils and fats	Cost of a healthy diet	% people unable to afford a healthy diet
Angola	1.01	0.84	0.40	1.20	0.72	0.17	4.33	81.4
Botswana	1.10	0.39	0.40	0.80	0.80	0.14	3.62	63.2
Eswatini	1.14	0.51	0.34	0.77	0.52	0.15	3.43	77.1
Lesotho	1.17	0.46	0.36	0.79	0.84	0.15	3.77	83.2
Malawi	1.09	0.33	0.13	0.61	0.40	0.18	2.72	94.5
Mozambique	0.99	0.41	0.21	0.84	0.39	0.19	3.03	91.2
Namibia	0.74	0.57	0.19	0.83	0.81	0.12	3.26	55.4
South Africa	1.06	0.63	0.85	0.70	0.73	0.13	4.10	65.3
Zambia	0.91	0.81	0.23	0.63	0.37	0.13	3.09	88.5
Zimbabwe	0.95	0.55	0.33	0.97	0.51	0.14	2.20	67.8

Data source: FAOSTAT suite of cost and affordability of a healthy diet (CoAHD) (6).

3.2.2 Protein supply

The average protein supply *per capita* per day and the average protein supply of animal origin for the 10 African countries are shown in Figure 4. South Africa had the highest average protein supply of 79.70 g *per capita* per day, with a substantial portion (36.00 g) originating from animal sources. Malawi and Botswana also had relatively high average protein supplies, with values of 71.00 g and 70.70 g, respectively, with a significant contribution from animal-origin protein. Mozambique had the lowest average protein supply at 45.30 g, with only 7.00 g from animal sources. Notably, the contribution of animal-origin proteins varied, with South Africa, Botswana, and Namibia showing the highest values.

3.3 Contribution of fish to food and nutrition

The dietary patterns related to animal protein and fish consumption across the selected countries are shown in Table 4. Angola and Mozambique showed relatively higher dietary animal

protein intake (14.00 g/person/day and 7.40 g/person/day, respectively), with Mozambique having a substantial *per capita* fish share of 53.70%. On the other hand, Malawi had a high fish and seafood liking index (99.70) against Africa's average of 75.5 coupled with significant fish consumption (23.20% *per capita* fish share). Botswana and Lesotho exhibited lower *per capita* fish shares (2.40 and 4.70%, respectively), indicating a lesser reliance on fish in their diets. South Africa stood out with the highest dietary animal protein intake (41.10 g/person/day) and a relatively low *per capita* fish share (4.40%). The fish and seafood liking index provided an interesting perspective, with Mozambique, Angola, and Malawi exceeding the African average.

3.3.1 Fish production by country

Figure 5 illustrates the quantities of fish production in tons from capture fisheries and aquaculture in the 10 Southern African countries from 2011 to 2021. South Africa consistently led in capture fisheries production, reaching 622,090 tonnes in 2016 and maintaining relatively high levels thereafter. Mozambique also showed a substantial increase, reaching 329,670 tonnes in 2020. Angola exhibited fluctuations, with a

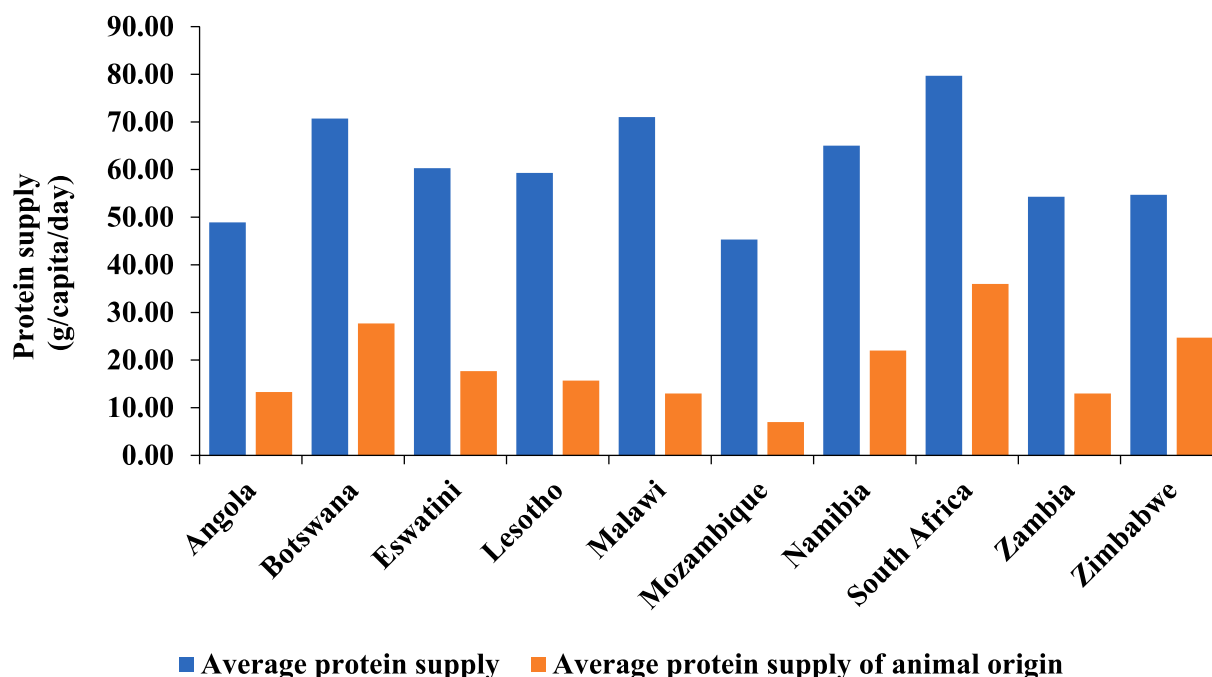


FIGURE 4

Estimated average animal protein supply by country in Southern Africa (2018–2020). Data source: FAOSTAT New Food Balances (6), (accessed on December 15, 2023), licensed under CC BY 4.0.

TABLE 4 Contribution of fish to food and nutrition security by country in 2021.

Country	Dietary animal protein intake (g/person/day)	Fish share (%)	Per capita fish consumption (Kg/person/year) ¹	Fish and Seafood liking index (Africa average = 75.5; global = 100) ²
Angola	14.00	29.80	14.20	129.00
Botswana	26.70	2.40	2.40	17.40
Eswatini	19.80	6.00	4.20	16.40
Lesotho	18.10	4.70	2.90	15.30
Malawi	12.90	23.20	10.10	99.70
Mozambique	7.40	53.70	13.90	125.20
Namibia	25.90	13.20	11.70	67.80
South Africa	41.10	4.40	6.60	32.30
Zambia	12.70	30.60	13.10	72.90
Zimbabwe	24.70	3.50	2.00	30.00

¹Data accessed from country based WAPI sheets (80).

²Cai and Leung (81); FAOSTAT New Food Balances (accessed on December 15, 2023).

peak of 531,575 tonnes in 2017. Malawi, on the other hand, experienced a decline from 2015 to 2020. Despite variations in individual country trends, the overall total fish production from capture fisheries across these nations remained relatively stable over the 2011–2021 period, ranging from approximately 1.7 million tonnes to 2.2 million tonnes. Zambia consistently dominated aquaculture production, reaching 63,355 tonnes in (15), followed by Zimbabwe and Malawi. The results indicate an overall upward trend in aquaculture production across the region, with notable increases in Zambia. While some countries, such as Lesotho, Eswatini, and Botswana, maintain relatively low production levels.

3.3.2 Aquatic products trade

The volumes of aquatic products for both exports and imports (in metric tonnes) across the 10 Southern African countries from 2011 to 2021 are presented in Figure 6. South Africa experienced a notable increase in aquatic product exports, reaching a peak of 205,840 metric tonnes in 2016, before gradually declining to 182,736 metrics tonnes in 2021. Meanwhile, Mozambique consistently contributed a significant volume, ranging from 8,222 metric tonnes in 2011 to 9,250 metrics tonnes in 2021. Angola also demonstrated growth in this regard, with its aquatic product exports increasing from 5,084 metric tonnes in 2011 to 18,337 metric tonnes in 2021. Conversely, countries

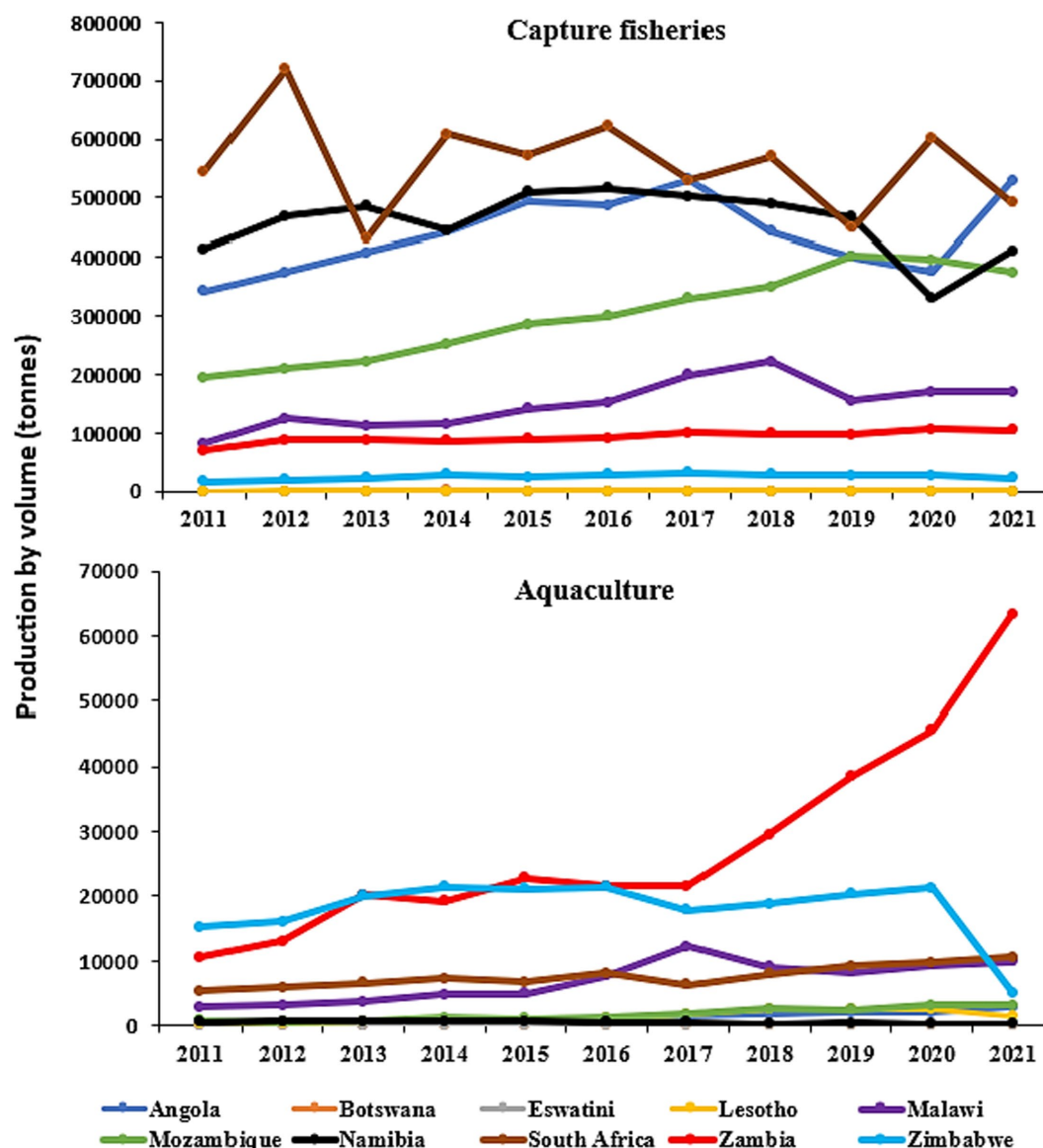


FIGURE 5

Capture fisheries and aquaculture production by country in Southern Africa, 2011–2021. Data source: FAO fishery and aquaculture statistics, global fisheries and aquaculture production (79); FAOSTAT, licensed under CC BY 4.0.

like Botswana and Eswatini contributed relatively small volumes, while others, including Namibia and Zambia, showed fluctuations.

The volume of aquatic product imports varied across countries during the same period. Angola maintained a high volume of imports throughout the period, peaking at 229,849 metric tonnes in 2014 and declining to 9,885 metric tonnes in 2021. Mozambique also exhibited substantial imports, with the highest volume of 59,112 metric tonnes recorded in 2021. South Africa consistently imported a significant amount of aquatic products, peaking at 276,770 metric tonnes in 2018. By contrast, countries such as Botswana, Eswatini, Lesotho, and Zimbabwe generally had lower import volumes in the region. Overall, the regional total import volume fluctuated over the years, reaching a peak of 597,051 metric tonnes in 2014, and slightly decreasing to 436,222 metric tonnes in 2021, to which Angola's large drop in its import are largely noticeable.

In general, the data indicate a trend of decreasing exports, coupled with increasing imports for most of the countries in Southern Africa.

4 Discussion

4.1 Food and nutrition security status

The pursuit of global food stability is a complex endeavor influenced by a diverse array of factors impacting production, supply, and consumption dynamics (16). Several factors, such as population growth, *per capita* income growth, inflation, and urbanization, strongly influence food demand [(17, 18, 90)]. In the Southern African region, the population is growing rapidly, with more than a 20% growth rate recorded between 2011 and 2021 in the selected countries

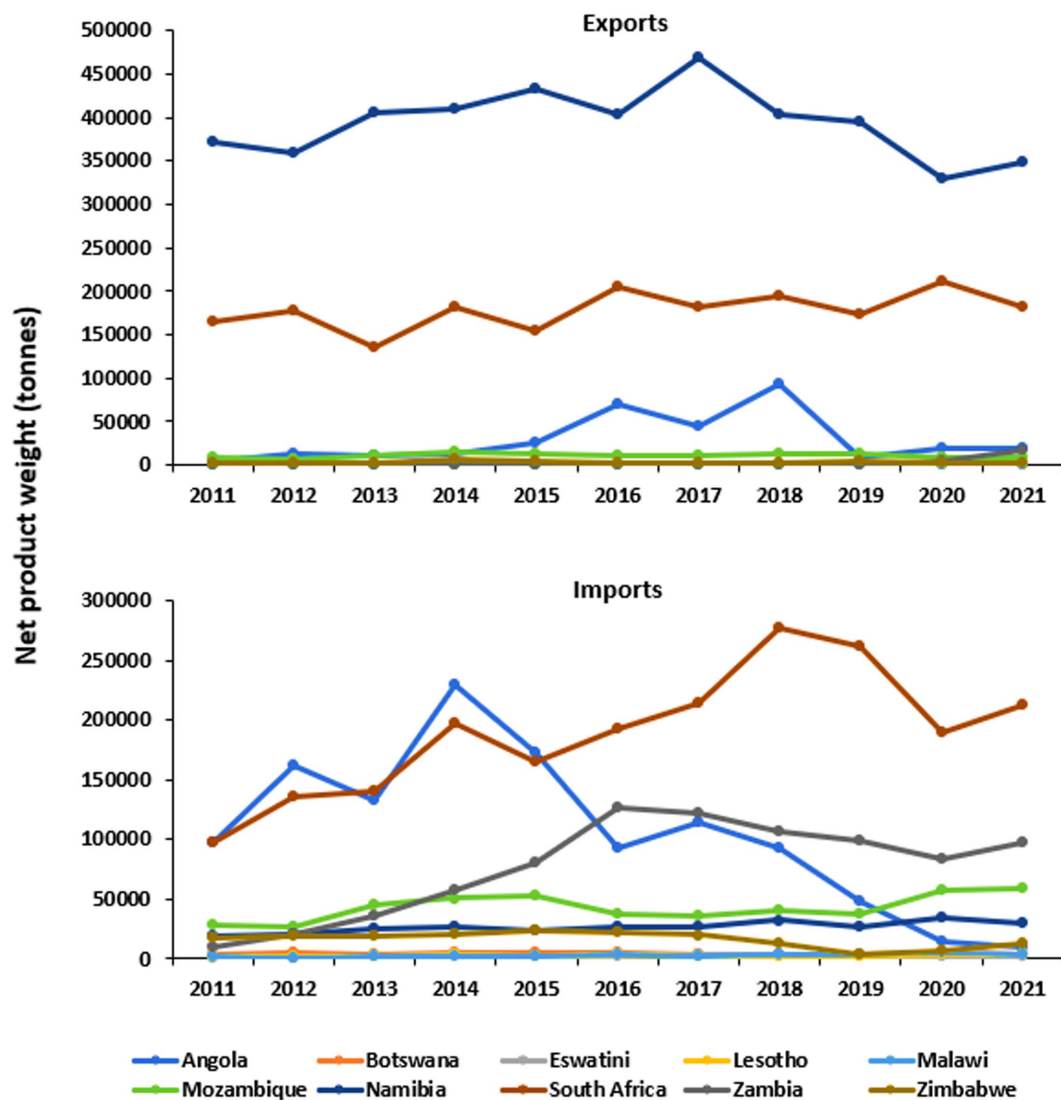


FIGURE 6
Aquatic products trade by country in Southern Africa, 2011–2021. Data Source (80); FAOSTAT, licensed under CC BY 4.0.

except for Namibia, Lesotho, South Africa, and Eswatini. During the same period, higher growth rates were observed in urbanization than in the total population or rural population across the countries. The results suggest a general trend toward urbanization across the countries, reflecting ongoing demographic shifts and the associated challenges and opportunities for urban development and resource allocation. The current study further revealed that countries with higher urban populations also had higher GDP, suggesting higher *per capita* income growth, which is likely to increase the food demand especially for nutritious diets in the region.

A significant proportion of the population across the studied countries is affected by food and nutrition insecurity. Except for South Africa and Eswatini, the prevalence of severe food insecurity surpassed the African average by 23.4% between 2020 and 2022. Similarly, the incidence of undernourishment exceeded the African average of 19.27%, except for South Africa, Namibia, Malawi, and Eswatini. Notably, Malawi had the highest prevalence of severe food insecurity, affecting over 50% of its population, whereas Lesotho

exhibited the highest incidence of undernourishment, affecting nearly half of its population. While many challenges in the region are similar, the degree of impact varies across countries, revealing differing levels of vulnerability to food insecurity. For example, in countries such as Malawi and Mozambique, where the prevalence of food insecurity was the highest, climate shocks have exerted a significant adverse impact on rain-fed agricultural systems and fish production (19, 20). An estimated 800,000 hectares of standing crops have been destroyed by cyclones and related floods that occurred in 2019 in Mozambique, Malawi, and Zimbabwe, affecting approximately 3.2 million people in these countries (21). A study conducted by Muhala et al. (22) in Mozambique revealed that cyclones Kenneth and Idai, which struck in 2019, resulted in the destruction of approximately 2,457 fishing vessels and equipment, 169 fishponds, 206 cages, 58 fish tanks, and fish seed stocks totaling 863,500 units. Additionally, many countries in the region depend heavily on rain-fed agriculture, making them particularly susceptible to the impacts of climate change.

Nutritional challenges are also highly prevalent in Southern Africa, including high rates of stunted growth in children and anemia among women of reproductive age. Despite progress in maternal, infant, and young child nutrition (MIYCN) across the region, reducing anemia prevalence among women of reproductive age remains a challenge (1). A key contributing factor to these challenges is likely low dietary diversity, where diets primarily consist of carbohydrate-based meals with minimal consumption of protein-rich foods of animal origin. In Malawi for instance, most people primarily consume cereals, grains, and legumes, whereas protein-rich foods such as fish, red meat, and eggs are consumed sparingly (23). Mozambique exhibits inadequate dietary quality, largely reliant on staple foods, leading to a deficiency in essential micronutrients, thereby exacerbating the prevalence of stunting in children (24). Heavy reliance on starchy staples leads to significant disparities in the consumption of healthy food groups, with variations in magnitude influenced by factors like household location and economic status (25). This challenge is often compounded by poor nutrition governance and high poverty levels, which hinders people's ability to provide affordable and accessible dietary diversity. For example, Eswatini has moderate nutrition governance through initiatives like micronutrient supplementation and malnutrition treatment, but lacks national dietary guidelines, limiting practitioners' ability to offer tailored advice (26).

Poverty is a major hindrance to food access in most countries in the region, evident in the alarmingly high percentages of the population living below the poverty datum line (92). Poverty affects access to not only quantity but also quality foods. The onset of the COVID-19 pandemic further exacerbated poverty across many nations, with greater impacts experienced in developing countries (27, 28). As a result, food shortages are becoming even more prevalent in many countries in Southern Africa. Additionally, social conditions, such as health, nutrition, education, and housing, influence productivity, thus affecting the poverty status of communities. In turn, social conditions are influenced by poverty, affecting households' ability to improve their productivity (9). Improving food security and nutrition in the region requires comprehensive efforts to enhance resilience in food production, promote inclusive policies, and improve economic conditions.

4.2 Nutritional and social benefits of fish consumption

Sufficient protein consumption is crucial for overall human health and growth (29). Animal source foods (ASFs) are considered superior for human nutrition and health due to their well-balanced amino acid profile and ease of digestion compared to other protein sources. In contrast to plant-based foods, ASFs provide larger amounts of superior-quality proteins, along with enhanced bioavailability of vitamin A, vitamin D3, iron, iodine, zinc, calcium, folic acid, and essential fatty acids (30). The World Health Organization (WHO) identifies ASFs as the optimal source of nutrient-dense nourishment, especially for children between the ages of 6 and 23 months (31). However, ASFs stand out as the most expensive food items consumed in Southern Africa, with over 50% of the population across countries unable to afford a nutritious diet. Of note were the alarming rates observed in Malawi and Mozambique, where over 90% of the

population faced this challenge, coinciding with the countries experiencing the highest levels of poverty. As cost and affordability are significant barriers hindering consumers' access to nutritious foods (32), it is imperative to address cost issues to encourage the consumption of ASFs within the Southern African region.

Fish, being a relatively cheaper protein source, contributes significantly to nutrition security beyond providing calories and proteins (11). It is also a source of essential fatty acids, particularly omega-3 polyunsaturated fatty acids (PUFAs) like docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) which promote brain development, cognitive function, and overall growth (10). Small pelagic fish such as *Engraulicypris sardella* (locally known as Usipa/bonya) common in Malawi and *Limnothrissa miodon* (Kapenta) found in Zimbabwe and Zambia, stand out as some of the most affordable options and are also exceptionally rich in long-chain polyunsaturated fatty acids (LC-PUFAs) (11, 33). Therefore, promoting fish consumption can help address nutritional challenges in the Southern African region.

Additionally, fish are a source of essential micronutrients, including vitamins D, A, and B (with B12 being associated with seafood), as well as minerals, such as calcium, phosphorus, iodine, zinc, iron, and selenium (14, 90). In pregnant women, vitamin D deficiency is associated with an increased risk of preeclampsia, gestational diabetes, preterm birth, and low birth weight (34). Vitamin A deficiency, a leading cause of preventable childhood blindness, weakens the immune system and contributes to anemia, while vitamin B is crucial for preventing anemia as well as neurological and cognitive issues (34, 90). Fish can help address iron deficiency, which leads to anaemia, a widespread problem in women of reproductive age in Southern Africa. Zinc, which is also highly available in fish, is vital for growth, development, and immune function, and its deficiency is linked to the prevalence of child stunting (89). Therefore, pregnant, and lactating women, infants born through breast milk, young children, and those vulnerable to malnutrition can benefit from fish consumption, thereby reducing maternal and child mortality risks.

In a comprehensive analysis pooling prospective studies and randomized clinical trials, Mozaffarian and Rimm (35) associated fish consumption with a 36% reduction in heart disease and heart attacks and a 12% reduction in overall mortality. Fish offer a comprehensive nutritional package with potential health benefits across various populations and age groups (34). Despite variations in nutritional content (e.g., fatty acid profile) among fish species owing to factors such as seasonality, habitat, trophic level, and diet (34, 36, 37), fish remain a nutritious food item with the potential to curb hunger and nutritional challenges in developing countries. Recognizing the nutritional value of fish is crucial for advocating diverse and balanced diets in the region. However, formulating targeted nutritional policies and interventions to address food insecurity and nutritional deficiencies requires a better understanding of variations in fish consumption across the region.

Furthermore, there is a need to recognize the multifaceted contribution of fish to food and nutrition security, beyond direct consumption. Fish also indirectly contribute to food and nutrition security through income generation, although this pathway is often neglected when assessing the contribution of fish (14, 38, 39). The income generated from fish production allows households to enhance their purchasing power for additional nutritious food (34, 40, 41). Fish creates employment opportunities, particularly for women involved

in various stages of the value chain, including the production, processing, and trading of fish and fish products.

In Southern Africa, fisheries and aquaculture provide employment for an estimated 3.3 million individuals, constituting approximately 1% of the total population (42). As the demand for fish continues to escalate, it will be necessary to boost fish production, consequently expanding employment opportunities and granting employed households the opportunity to enhance their food and nutrition security capacity. Nevertheless, the multitude of pathways through which fish contribute to food security and nutrition complicates the quantification of their overall impact (34). Thus, the empirical link between fish production and food security warrants further investigation, considering various pathways beyond direct fish consumption.

4.3 Fish consumption in Southern African

Fish consumption in the Southern African region varies across countries mainly due to factors such as availability, accessibility, and affordability. In countries like Angola, Mozambique, Zambia, Malawi, and Namibia, *per capita* fish consumption exceeded the regional averages of 8.3 kg/person/year for sub-Saharan Africa and 10.0 kg/person/year for Africa in 2019. Fish contributes a significant share of the dietary animal protein consumed in these countries, aligning with higher liking indices for fish and seafood. In Angola, fish provide approximately 30% of the population's animal protein intake despite persistent nutritional challenges in rural areas due to poor access to fish products (9). Mozambique relies on fisheries for income and sustenance, with fish accounting for approximately 53% of the nation's total animal protein consumption. Similarly, Zambia benefits around 30% of the national dietary animal protein from fish consumption and the *per capita* fish consumption is projected to rise by 2030 (43). In Malawi, approximately 23% of the animal dietary protein consumed is supplied by fish (more especially the small fish species, i.e., *E. sardella*) despite reported variations across different socio-economic status groups and proximity to fishing areas (44). Namibia derives a relatively modest (13.20%) of its animal dietary protein from fish, but there is potential for this figure to rise, even though certain regions within the country encounter difficulties in both accessing and affording fish products (45). Surprisingly, these countries, except for Namibia also exhibit higher prevalence rates of stunting in children and anaemia in women of reproductive age on average compared to countries with lower reliance on fish for dietary protein in the region. This highlights the importance of sufficient variety in diet, the opposite of which is widely recognized as a key factor in determining stunted growth in children (46, 47).

Troell et al. (37) also noted that the overall benefits of integrating fish into one's diet depend largely on the balance of other dietary components and whether essential macronutrients and micronutrients are already being adequately consumed to meet daily requirements. A study conducted in Zambia's most fish-consuming region observed that despite high consumption rates of fish, stunting in children persisted, mainly due to low dietary diversity (48). Promoting the consumption of a variety of foods, including vegetables, fruits, and animal products, in early childhood can enhance growth and development (49).

Marinda et al. (50) associated stunting in children with the quality of fish consumed which highlights the significance of producing and consuming quality fish. Several factors can compromise the quality of fish consumed, including post-harvest losses, environmental factors, and contamination by pollutants, such as heavy metals and pesticides (11, 51, 52). In Lesotho, fish consumption patterns are influenced by availability and affordability of widely accessible imported canned and frozen fish products (42, 53). Similarly, fish consumption in Malawi is influenced by proximity to fishing areas (44). Disparities in national fish consumption, with coastal communities consuming higher quantities in their diets, have been noted in several countries, including South Africa, Namibia, and Angola (45, 54, 55). Thus, fish consumption patterns across the region are predominantly shaped by accessibility and affordability, underscoring the necessity of national and regional initiatives to guarantee accessibility to fish products by all groups of society.

The current study further revealed a general trend of increasing imports and decreasing exports of aquatic products during the 2011–2021 period, reflecting the increasing demand for fish products resulting from a growing population. The data also highlight the importance of aquatic product imports in meeting national fish demand in the region where regional markets play an increasingly important role (42). A slight decline in both categories was observed after 2018 for most countries, which is likely due to the COVID-19 pandemic that restricted fish trade not only in the Southern African region but also in the global market. Therefore, there is a need to strengthen food systems using resilience measures to ensure the uninterrupted provision of nutritious foods in the face of global pandemics and environmental shocks. In fishery-dependent communities, ineffective strategies for diversifying food sources exacerbate the overexploitation of wild fishery resources, leading to detrimental effects on both current and future fish consumption patterns (9). Intentional policies that encourage and maintain the diversification of food sources other than fish products will supplement and maintain the production, distribution, utilization, and ultimately the consumption of nutritious foods in the region.

4.4 Overview of fish production in the region

With the global population expected to surpass 9 billion by 2050 (4), the paramount concern revolves around the impact of this growth on food security dimensions, including availability, accessibility, utilization, and stability. Particularly noteworthy is the projected population rise in Sub-Saharan Africa, a region that is already struggling with high levels of food insecurity and malnutrition. Hence, it is imperative to carefully examine the future of fish production, discerning its potential to substantially alleviate and mitigate these complex challenges.

4.4.1 Capture fisheries

Fish production in the Southern African region is primarily driven by capture fisheries, in line with broader continental trends (13, 82). Challenges, such as overexploitation in capture fisheries, persist, highlighting the importance of sustainable management practices. While capture fishery production has shown relative stability across countries over the past decade, the increasing demand for aquatic products cannot

be sustained solely by reliance on capture fisheries. This is particularly significant as populations have grown in all the countries during the same period. Notably, Mozambique has experienced notable growth, signalling its emergence as a significant player in the regional fisheries sector. The country boasts extensive fishery resources and a thriving fishery sector, with significant potential for growth in both domestic and foreign markets (42). Similarly, Angola's fisheries sector continues to be vital for the national economy despite facing challenges such as overfishing and hydrological changes (55). Malawi's capture fisheries sector, encompassing both small-scale and large-scale operations, contributes to over 90% of the nation's fish production, with Lake Malawi alone accounting for more than 90% of the total catch (56). Recent increases in fish catches have been observed in Malawi, but their implications remain unclear due to concurrent changes in species composition (57). Zambia's abundant freshwater resources, spanning approximately 15 million hectares, offer significant potential for the development of its capture fisheries sector. Nevertheless, the industry has faced challenges, such as overexploitation and the impacts of climate change, resulting in stagnant production in recent decades (43). Botswana faces challenges in monitoring and reporting fish production, leading to inaccurate current estimates. For instance, production from major fishery resources in the country, such as the Okavango Delta, has remained unreported since 2017, highlighting the need for improved data-collection mechanisms (58). Away from the seashores that Mozambique, Namibia, and Angola comparatively and competitively enjoy, Zambia, Zimbabwe, and Botswana, share the benefits of the Zambezi River that enhance fish production and trade on their borderline corridors.

Lesotho's capture fishery relies largely on hook and line fishing, with ongoing efforts to expand aquaculture production, promising growth for the sector, albeit with management challenges. Zimbabwe fishery sector primarily includes commercial, artisanal, and recreational fishing operations focused on lakes, particularly Lake Kariba, and is complemented by smaller water bodies for subsistence fishing (59, 84). Namibia's fishing industry benefits from the productive Benguela Current System, although challenges such as pilchard depletion persist, and efforts to increase marine aquaculture production align with long-term sustainability goals. Besides, Namibia boasts of a highly commercialized and well-managed fishing industry in the region, contributing significantly to national and regional fish production (45, 60). Lesotho and Eswatini have minimal fisheries development due to their limited water resources, primarily consisting of rivers and small reservoirs, which are suitable mainly for subsistence fishing activities (42). South Africa's extensive capture fisheries sector includes commercial, recreational, and subsistence fishing, with the commercial segment comprising highly industrialized offshore fisheries and more traditional near-shore fisheries with lower capital requirements (55). The observed fluctuations in capture fishery production in the region reflect the complex interplay of environmental factors, fishing practices, and management strategies. Understanding these trends is essential for sustainable fisheries management, ensuring food security, and addressing economic implications within the region.

4.4.2 Aquaculture

Aquaculture across the Southern African region remains in its infancy stages, with varying degrees of development and challenges across countries. However, Zambia's aquaculture production, ranked 5th in Sub-Saharan Africa and leading in Southern Africa,

is experiencing significant growth and is soon to outpace capture fisheries production, driven by strong government support, private investments in cage aquaculture, and the abundance of water resources (61, 62, 91). Zimbabwe, ranked among the top 10 aquaculture producers in sub-Saharan Africa, shows promise for further expansion due to growing support from both government and donor-funded initiatives (63). Similarly, Botswana's growing aquaculture sector exhibits significant potential for future expansion, propelled by rising investments, primarily from the private sector. Malawi's aquaculture production remains modest, accounting for approximately 5% of the nation's total fish production (57). However, governmental and support agencies are increasingly acknowledging their potential. In Angola, aquaculture production is predominantly small-scale, centered on communal ponds for local consumption; nevertheless, there is a discernible increase in medium to large-scale commercial operations (54). Additionally, ongoing efforts are underway to promote shrimp aquaculture production through sustainable resource exploitation.

Eswatini's aquaculture sector is currently underdeveloped, but there is potential for increasing tilapia production, contingent upon the formulation of a national aquaculture strategy to guide sectoral growth (90). Aquaculture in Mozambique holds vast untapped potential to become a key economic driver, despite facing challenges such as infrastructure deficiencies, limited access to inputs, and low yields (22). Aquaculture in South Africa comprises freshwater and marine sectors, with freshwater limited by the water supply and marine experiencing rapid growth, particularly focusing on high-value species (64, 65). The overall upward trajectory in aquaculture production in the region suggests growing recognition of the importance of aquaculture in meeting the demand for fish products, improving food security, and contributing to economic development. The statistics also highlight the variability in aquaculture development among these nations, which is influenced by factors such as investment, infrastructure, and government policies. Sustainable management practices and collaboration between countries could further enhance the positive impact of aquaculture on regional economies and food systems.

4.4.3 Challenges

The Southern African countries face multifaceted challenges in their fisheries and aquaculture sectors. These challenges range from overfishing, infrastructural limitations, and outdated legislation to environmental impacts such as climate change. Overfishing, driven mainly by a growing population, is a major challenge leading to stagnated production in capture fisheries in many countries in the region, including Zambia, Zimbabwe, Malawi, Namibia, and Angola. Emerging challenges such as climate change could significantly affect fish populations, distribution, and productivity, although the extent of its effects is not clearly understood due to lack of quantification. The decline in aquaculture production in Mozambique, Malawi, and Zimbabwe has been attributed to climate-associated events such as cyclones, droughts, and flooding (20, 57). Furthermore, these events are widespread in several Southern African countries, including Eswatini, Mozambique, and South Africa, with varying impacts on fish production (66, 67). These challenges are likely to exacerbate the mismanagement of fishery resources (68). Additionally, a mounting challenge arises from invasive species in many key fishery resources, particularly in

shared water bodies like Lake Kariba and the Zambezi River basins (69). This threat negatively impacts capture fisheries production, biodiversity, and aquaculture breeding programs, particularly due to the risk of interspecific hybridization with indigenous species.

Consequently, deficiencies in essential micronutrients and fatty acids are likely to worsen with declining capture fisheries production, considering that the sector is the major supplier of fish food in Southern Africa. Management measures are present in all countries except Lesotho and Eswatini; however, enforcement is weak across countries. Addressing these challenges requires comprehensive governance, and technological changes to ensure the continued contribution of capture fisheries to food security. For instance, inadequate port facilities, postharvest losses, and high operational costs in aquaculture hinder fish production growth in Angola, whereas fragmented extension services, climate change, and governance issues impede sectoral development in Botswana [(70, 71)].

Malawi encounters various management challenges, such as overexploitation, over-capitalization, illegal, unreported and unregulated (IUU) fishing, conflicts with industrial fisheries, and post-harvest fish losses (56, 72). Mozambique's challenges include a lack of skilled personnel and damage from natural disasters (20), while Zambia struggles with overexploitation and regulatory conflicts in fisheries and limited access to capital and expertise in aquaculture. Zimbabwe's fisheries and aquaculture sectors suffer from the absence of a comprehensive policy framework and various operational challenges, including input shortages and infrastructure deficiencies (63). Lesotho face challenges such as a shortage of trained personnel and limited funding, whereas Namibia contends with external factors such as climate change, volatile fuel prices and conflicts with mining activities that mainly affect capture fisheries (73). In South Africa, overexploitation and environmental concerns threaten marine resources, while regulatory complexities and economic hurdles constrain aquaculture expansion. Eswatini faces challenges, such as limited fisheries and aquaculture development, mainly due to limited access to water resources, leading to low investments in the sector (SADC, 2021).

Major challenges facing the aquaculture industry in the region are generally the same and include the high cost of quality fish feeds, poor quality fish seed, and low investment in the industry. In addition, fish diseases are emerging in the region and will have adverse effects on fish production as aquaculture production expands (57). These challenges are further exacerbated by the lack of appropriate technological advancements and inadequate research, coupled with inadequate government support in research and development. Moreover, aquaculture is poorly integrated with other food production systems to enhance productivity. Despite the potential benefits of integrating aquaculture with crop and livestock production, there is limited investment in the sector, compounded by a lack of development infrastructure, credit lines, information, training, and expertise across the region. Notwithstanding the favorable climate in the region for cultivating potential aquaculture species, limited progress has been made in this direction.

4.4.4 Opportunities

Despite the challenges highlighted above, opportunities to promote fish production from fisheries and aquaculture exists across the region. Countries such as Angola, Mozambique, South Africa, and Namibia boast extensive coastline lengths and inland water surface areas, providing abundant opportunities for marine and freshwater fisheries. These resources, coupled with

substantial renewable water reserves, contribute to the robust fishery sectors and support food security initiatives through the availability of diverse aquatic resources. For instance, Mozambique's diverse natural environments and comprehensive legal frameworks support both marine and inland fisheries, with aquaculture playing an increasingly significant role. Angola's rich marine ecosystem and coastal resources present vast opportunities for fisheries development (55). South Africa's fishing and aquaculture sectors, although relatively small in GDP contribution, hold the potential for expansion and sustainability through initiatives promoting sustainable practices and species diversification. Furthermore, Namibia, benefiting from productive fishing grounds and effective management systems, aims to increase aquaculture production and enhance export earnings through the strategic initiatives outlined in its Vision 2030 and Master Plan for Aquaculture (FAO, 2024). In its nascent phase, Namibia's mariculture sector holds promise for making a substantial contribution to food security (74). Conversely, landlocked countries, such as Botswana, Eswatini, Lesotho, Malawi, Zambia, and Zimbabwe, have limited access to coastal or marine water bodies, impacting their fishery potential. However, efforts to harness alternative water sources and promote sustainable aquaculture practices can contribute to food production and livelihoods in these regions. Botswana's ephemeral water bodies (i.e., dams, swamps, and floodplains) and main rivers offer favorable environments for fish productivity (75, 76), whereas Malawi, despite persistent climate-related challenges, has the potential to expand aquaculture production owing to its abundant land and water resources. Kaimila et al. (77) estimated that 15–20% of the land in Malawi is suitable for aquaculture production besides underutilized for cage aquaculture on Lake Malawi. With its newly launched fisheries and aquaculture policy, Zambia is promoting aquaculture through various projects and initiatives to enhance production and improve food security and livelihoods. Zimbabwe, facing a significant deficit between fish demand and supply, highlights opportunities for aquaculture expansion supported by abundant land and water resources and government commitment, while Eswatini aims to tap into its favorable climate for tilapia cultivation through strategic planning and support from organizations such as the FAO (67). Lesotho's aquaculture industry, although currently small in scale, possesses notable economic significance, primarily attributable to the cultivation of high-value species, such as trout (65). Moreover, the geographic features of Zimbabwe and Lesotho offer two distinct prospects for fish farming: highlands with warm water temperatures exceeding 24°C, ideal for cultivating warm water species such as tilapia, and lowlands with cooler temperatures providing suitable conditions for rearing high-value cold-water species such as trout (53, 78).

Given the unlikely prospect of increased capture fisheries in keeping pace with population growth, aquaculture emerges as the primary avenue for sustainably boosting fish production in the region. This acknowledgment is widespread among governments and is evident in the recognition and prioritization of aquaculture initiatives. Moreover, the Southern African Development Community (SADC) has developed a regional aquaculture strategy and action plan (RASAP) that envisions the region as a leader of sustainably produced aquaculture products in Africa to contribute significantly to food security, employment, poverty alleviation, and economic growth

across the region by 2025 (85). However, achieving this will require fostering science and technology sharing, strengthen research collaborations, and establish conducive environments for both public and private investments across key industries, such as fish seed production, feed technology, fish processing, and trade.

5 Conclusion

This study investigated the contribution of fish to food and nutrition security in Southern Africa and highlighted the challenges and opportunities in fish production. The study revealed that severe food insecurity and high prevalence rates of stunting in children and anaemia in women of reproductive age remain major challenges affecting the region. Fish consumption has emerged as a critical component for addressing these challenges, offering a rich source of essential nutrients and potential economic benefits through aquaculture and fisheries. However, disparities in access, affordability, and dietary diversity persist across the region, necessitating targeted interventions to promote equitable access to nutritious foods including fish products. Furthermore, the Southern African region offers diverse opportunities for advancing fisheries and aquaculture to contribute to economic development, poverty alleviation, and food security. Understanding and leveraging the diverse hydrological landscapes across the region is crucial for optimizing food and fish production, ensuring resilience in the face of environmental challenges, and advancing sustainable development goals. However, the potential of capture fisheries and aquaculture to enhance food security and contribute to macro-economic development hinges on effective governance mechanisms and tailored policy interventions, which vary across countries.

Author contributions

SM: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing, Data curation, Writing – original draft. CoM: Data curation, Validation, Writing – original draft, Writing – review & editing, Project administration. MMo: Data curation, Supervision, Validation, Writing – original draft, Writing – review & editing. TN: Data curation, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing. NG: Data curation, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing, Project administration. JM: Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. MP: Data curation, Supervision, Validation, Writing – original draft, Writing – review & editing. VM: Data curation, Validation, Writing – original draft, Writing – review & editing. MMA: Data

curation, Validation, Writing – original draft, Writing – review & editing. MN-M: Data curation, Supervision, Validation, Writing – original draft, Writing – review & editing. OH: Data curation, Validation, Writing – original draft, Writing – review & editing. TB: Data curation, Validation, Writing – original draft, Writing – review & editing. MMu: Data curation, Validation, Writing – original draft, Writing – review & editing. VE: Data curation, Validation, Writing – original draft, Writing – review & editing. WJ: Data curation, Validation, Writing – original draft, Writing – review & editing. CD: Data curation, Validation, Writing – original draft, Writing – review & editing. ChM: Data curation, Validation, Writing – original draft, Writing – review & editing. MB: Data curation, Validation, Writing – original draft, Writing – review & editing. JL: Data curation, Supervision, Validation, Writing – original draft, Writing – review & editing. ES: Data curation, Supervision, Validation, Writing – original draft, Writing – review & editing. LZ: Data curation, Methodology, Validation, Funding acquisition, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Impact of major emergencies on zero hunger, achieving food security, and improving nutrition

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Introduction: Food security is a common livelihood issue that has received much attention from countries all over the world. Thus, researching the impact of COVID-19 on eradicating hunger, achieving food security, and improving nutrition can provide experiences for effectively responding to future emergencies that may affect food security.

Research and methods: Previous studies on the impact of COVID-19 on food security are less concerned with its impact on improving nutrition, therefore, this paper opens the black box of the process of eliminating hunger, reaching food security and improving nutrition, and divides it into the agricultural production sub-stage and the elimination of hunger and improvement of nutritional sustainability sub-stage. On the other hand, most of the past studies are based on impact pathway analysis only, and lack the assessment of the degree of impact from a quantitative perspective. Therefore, this paper takes the data of 29 provinces in China from 2016 to 2020 as the object of the study to measure their total and sub-stage efficiencies in the process of eradicating hunger, reaching food security, and improving nutrition, and to explore the characteristics of their spatial distributions. Meanwhile, the focus is concentrated on the 2019–2020 window to explore the impact of COVID-19.

Result and discussion: Based on research findings, this paper puts forward policy recommendations such as establishing a sound natural disaster prevention and control mechanism and accelerating agricultural technological innovation in order to better reduce the negative impact of food security emergencies in the future.

KEYWORDS

food security, entropy, window two-stage DDF model, dynamic efficiency, nutritional sustainability

1 Introduction

According to the 2023 State of Food Security and Nutrition in the World report, there are currently about 735 million hungry people in the world, an increase of 122 million compared to before the outbreak of COVID-19 in 2019 ([World Health Organization, 2023](#)). There is a lot of evidence that major global emergencies such as COVID-19, extreme weather events, and the conflict in Ukraine will pose a major threat to the achievement of Sustainable Development Goal 2 (SDG2) of “Zero Hunger.” Taking COVID-19 as an example, it is estimated that the number of hungry people will increase by nearly 90 million in 2019–2020 alone. Moreover, the impact of such major emergencies on food security and improved nutrition is more serious in developing countries, with the proportion of hungry people in Africa approaching 20%, Asia 8.5%, and Latin America and the Caribbean 6.5% ([World Health Organization, 2023](#)). Therefore, how to recover from COVID-19 as soon as possible, reduce poverty and hunger, and achieve food security has become an important issue that has attracted close attention from the international community.

According to the definition of the United Nations World Food Security Committee, food security means that all people have physical, social and economic access to sufficient, safe and nutritious food at all times to meet their food preferences, eating habits and the needs of an active and healthy life. Global food security depends on the normal operation of the global food and agricultural supply system. The impact of COVID-19 on the global food supply chain is mainly through the following three channels. At the production level, anti-epidemic measures have restricted the flow of workers in the food and agricultural industry, exacerbated the shortage of agricultural labor, and made it difficult to purchase agricultural inputs needed for food production, resulting in production obstructions and affecting food production. At the circulation level, COVID-19 affects the circulation of food, especially the circulation of international food and agricultural trade, which has hit the enthusiasm of market players to participate in international trade and led to a reduction in trade and investment (Pavolova et al., 2021; Akbari et al., 2021); at the same time, the food export restrictions of some food exporting countries such as Russia and Belarus have caused sharp fluctuations in international food prices, disrupting the global food supply chain (Alpizar et al., 2011; Fukase and Martin, 2016). On the consumer side, under the influence of Covid-19, the world economic growth rate has dropped sharply and fallen into recession. The restrictions on the flow of people taken by various countries have caused the economy to stop, and production and work cannot be resumed quickly, resulting in reduced income, which affects the ability of vulnerable groups to obtain food (Balgah et al., 2023; Huang et al., 2023; Jin et al., 2022). From the above analysis, it can be seen that countries exhibited uneven levels of food security even before the outbreak of COVID-19, and that under the impact of COVID-19, any disruption in production, distribution, and consumption would lead to a break in a country's food supply chain.

Thus, safeguarding food production, effectively saving food and reducing losses, and upgrading the capacity of food reserves and management are very important for coping with the impact on food security of various emergencies such as COVID-19 (Hou et al., 2022; Kelsall et al., 2023; Lu et al., 2023). The resilience of a country's agri-food system is affected by climate conditions and natural resources, the level of agricultural science and technology and business models, agricultural support policies, public awareness of food security and other factors, and shows different resilience in response to shocks and pressures (Huang and Yang, 2017; Brown et al., 2017; Wang et al., 2018). Faced with an extremely unstable world food supply, as the world's largest food producer, China uses less than 9% of the world's arable land to produce about 1/4 of the world's food, solving the problem of feeding 1/5 of the world's population and making positive contributions to addressing global food security issues. In terms of improving nutrition, the nutritional level of Chinese residents has significantly improved, and the consumption structure has also changed significantly. The consumption of staple foods such as rice and wheat has gradually decreased, while the consumption of meat, poultry, eggs, milk and other animal foods has increased significantly (Patel and Shrimali, 2023; Qin et al., 2022). In response to major natural disasters and public safety incidents such as

COVID-19, China has established a complete emergency reserve system in large and medium-sized cities and areas where prices are prone to fluctuate, which can provide 10–15 days of emergency supply. All of the above shows that China has rich theoretical and practical experience in eliminating hunger, achieving food security and improving nutrition (Zivin et al., 2020; Yang, 2022). Research on relevant data in China will hopefully provide reference for developing countries.

Based on the above analyses, this paper explores the relationship between the stages of agricultural production and the sub-stages of hunger eradication, achieving food security, and improving nutrition in China and answers the following questions: (1) How to assess the efficiency of the process of agricultural production, hunger eradication, achieving food security, and improving nutrition? (2) To what extent does COVID-19 impact this process? (3) How can the efficiency of agricultural production be effectively improved to better contribute to eradicating hunger, achieving food security, and improving nutrition?

To address the above questions, this paper establishes the Entropy Window two-stage DDF model, divides the 2016–2020 period into window sub-periods of 2 years, measures the overall efficiency value of the process of eradicating hunger, achieving food security, and improving nutrition in the agricultural production of 29 provinces in China in each window and the efficiency value of the sub-stages, and conducts comparative analyses by stage, by region, and by province. The impacts of COVID-19 on hunger eradication, achieving food security, and improving nutrition are further explored based on the epidemic's 2019–2020 window. From an objective and comprehensive understanding of the current situation of China's food security, this paper offers targeted policy recommendations for the nation to ensure food security, improve agricultural production, eradicate hunger, and improve nutrition.

The rest of the paper runs as follows. Section 2 surveys the relevant literature on food security and presents the innovations of the paper. Section 3 describes the modeling process and the sources and methods of dataset creation. Section 4 provides an empirical analysis based on the results of the Entropy Window two-stage DDF model and explores in depth the impact of COVID-19 on eradicating hunger, reaching food security, and improving nutrition. Section 5 presents relevant policy recommendations.

2 Literature review

The concept of food security was first introduced by the Food and Agriculture Organization of the United Nations (FAO) at the World Food Conference held in Rome in 1974. Subsequently, the connotation of the concept has been enriched continuously, and research related to food security has also been deepened. Many scholars have focused on three main aspects of food security as follows.

Factors influencing food security. The literature on factors influencing food security mostly focuses on the status of natural resource endowment such as moisture, arable land, and light, as well as the status of human resources such as labor force and technology level. Abbas et al. (2023), Wu et al. (2023), and Amadou et al. (2021) examined the effects of climate change, the level of intensive land use, and digital technology on food security, respectively. Vochozka et al. (2020a, 2020b), on the other hand, pointed out that changes in the price of fossil fuels will also have an impact on the price of food, leading to food insecurity. Tang et al. (2015) conducted an empirical analysis based on China's macroeconomic data for 1978–2013, and the results showed that agricultural mechanization,

Abbreviations: COVID-19, Coronavirus disease 2019; DDF, Directional distance function; TOPSIS, Technique for order preference by similarity to an ideal solution; DEA, Data envelopment analysis; DMU, Decision making unit; GDP, Gross domestic product; ME, Mean efficiency; CR, Column range; CR_O, Overall column range; TR, Total range.

fertilizer, efficient irrigation, and food policy are important factors in reaching food security, while the role of *per capita* sown area of grain has been decreasing year by year. Some scholars have also analyzed the impact of major emergencies on food security. For example, [Lialina and Morachevskaya \(2022\)](#) argued that the impact of COVID-19 on food security manifested itself in a decline in people's income and an increase in food price.

Food security evaluation. Many scholars have used hierarchical analysis, entropy weight TOPSIS model, data envelopment analysis (DEA), and other methods for assessment of food security evaluation, among which the DEA method is the more commonly used method by many scholars. For example, [Hu et al. \(2021\)](#) used a three-stage DEA model to assess the efficiency of China's main grain producing areas for 2007–2019 after removing environmental factors and random variables; [Fu et al. \(2021\)](#) applied a DEA model to assess China's food security from the perspective of trade and concluded that the status quo of its heavy dependence on the international market for soybeans may bring a crisis to its food security. [Gokhan and Shannon \(2019\)](#) evaluated the food security of states in the United States over a 13-year period based on the DEA-Malmquist model and concluded that food security was improving during that time.

Risks and challenges to food security and measures to address them. Some scholars considered the changes in supply and demand brought about by declining yields and rising food prices in the international food market, the uncertainty of policies in various countries, and the high concentration of food exports and low concentration of imports as risk challenges to reach food security ([Zhang et al., 2014](#); [Zhang et al., 2022](#); [Zhong et al., 2018](#)). They then proposed countermeasures to these challenges. There are also scholars who focus on a specific type of challenge and propose corresponding solutions. For example, in improving agricultural science and technology, satellite forecasting can be used to detect crops ([Tanaka et al., 2023](#)), the role of big data and algorithms in predicting food prices can be utilized ([Valaskova et al., 2024](#); [Kliestik et al., 2024](#)), and the use of AI in agricultural production can be increased ([Kliestik et al., 2023](#); [Dvorský et al., 2023](#)). In terms of improving the environment for agricultural production, soil fertility can be restored through biochar ([Maroušek, 2014](#); [Maroušek et al., 2017](#)). Based on the coupling of the three systems of energy-water-food, [De Laurentiis et al. \(2016\)](#) proposed that achieving sustainable agricultural development, reducing food losses at all stages of production, and forming dietary habits that conserve food and reduce wastage are effective measures to cope with food risks.

The above literature has studied food security based on different perspectives and methods, which is an important reference value for understanding the current situation of food security and constructing a food security evaluation system, but there are still some issues that need to be further explored. First, when assessing food security, the literature is mostly based on food supply security, while the assessment of nutritional supply is missing. [Sajjad \(2017\)](#) proposed food security at the nutritional level is more of a health concern than at the yield level, and the lack of nutritional supply will lead to increased malnutrition rates. Second, the literature is mostly based on a static perspective to assess the current situation of food security in China, and it is difficult to conduct in-depth analyses of the characteristics of its temporal and spatial changes. Third, more scholars have analyzed the path of the COVID-19 epidemic's impact on food security, but fewer have quantitatively analyzed the extent of its impact based on mathematical models.

Therefore, this paper also incorporates the measure of improved nutrition into the evaluation system, subdividing reaching food security into two sub-stages of agricultural production stage and eradicating hunger and improving nutrition sustainable development stage. It uses the window analysis method, assesses the dynamic evolution perspective, and examines in-depth the extent of COVID-19's impact on eradicating hunger, reaching food security, and improving nutrition, in order to better examine the global perspective of the efficiency value changes and to more deeply delineate the temporal trends in food security levels.

3 Research methods

In order to better assess efficiency from a dynamic perspective, this paper combines the data envelopment analysis (DEA) model framework with [Charnes et al. \(1985\)](#) window analysis and [Shannon \(1948\)](#) entropy method to construct the Entropy Window Two-stage DDF model. Through the Entropy Window two-stage DDF model, an empirical study is conducted to investigate COVID-19's impact on the development efficiency of eradicating hunger, achieving food security, and improving nutrition (Stage 2) in 29 provinces of China. In the following, the Entropy method is introduced first, and then the Entropy Window two-stage DDF model is built, which is described as follows.

3.1 The entropy method

The improvement in nutrition is reflected in the following four aspects: (1) the incidence of stunting in children under 5 years of age, (2) the incidence of malnutrition in children under 5 years of age, (3) the incidence of obesity in children under 5 years of age, and (4) the incidence of neonatal visits. If these parallel indexes are put into the DEA model, there will be no solution problem. Therefore, the entropy method of [Shannon \(1948\)](#) was adopted in this model to fit the above four indicators, and a comprehensive indicator of improved nutrition (IN) was obtained. These are shown in [Table 1](#).

The Entropy method and steps are as follows.

Step 1: Data standardization. The following detailed indicator variables in the outputs of Stage 2 are calculated by [Equation 1](#): (1) stunting rate of children under 5 years of age, (2) malnutrition rate of children under 5 years of age, (3) obesity rate of children under 5 years of age, and (4) neonatal visit rate for the 29 provinces of China.

$$r_{mn} = \frac{\max_m x_{mn} - x_{mn}}{\max_m x_{mn} - \min_m x_{mn}} \quad (m = 1, \dots, 29; n = 1, \dots, N) \quad (1)$$

TABLE 1 Detailed indicators for stage 2.

Detailed indicator	Output item in stage 2
Prevalence of stunting among children under 5 years of age	Improved nutrition
Malnutrition rate of children under 5 years old	Improved nutrition
Obesity rate of children under 5 years old	Improved nutrition
Neonatal visit rate	Improved nutrition

Here, r_{mn} is the standardized value of the n^{th} indicator for the m^{th} province; $\min_m x_{mn}$ is the minimum value of the n^{th} indicator for the m^{th} province; and $\max_m x_{mn}$ is the maximum value of the n^{th} indicator for the m^{th} province.

Step 2: Sum the standardized values for the detailed indicators in Stage-2 output items by Equation 2.

$$P_{mn} = \frac{R_{mn}}{\sum_{m=1}^{29} R_{mn}} \quad (m = 1, \dots, 29; n = 1, \dots, N) \quad (2)$$

Here, P_{mn} denotes the ratio of the standardized value of the n^{th} indicator to the sum of the standardized values for the m provinces.

Step 3: Calculate the entropy value of the n^{th} indicator (e_n) by Equation 3.

$$e_n = -(\ln 29)^{-1} \sum_{m=1}^{29} [P_{mn} \ln(P_{mn})] \quad (m = 1, \dots, 29; n = 1, \dots, N) \quad (3)$$

Step 4: Calculate the weight of the n^{th} indicator (w_n) by Equation 4.

$$w_n = \frac{1 - e_n}{\sum_{n=1}^N (1 - e_n)} \quad (n = 1, \dots, N) \quad (4)$$

Using the above steps, we find out the weights and output values of the detailed indicators in the output items of Stage 2: (1) Prevalence of stunting among children under 5 years of age, (2) malnutrition rate of children under 5 years of age, (3) obesity rate of children under 5 years of age, and (4) neonatal visit rate for the 29 provinces of China. Based on the above entropy method, the Window two-stage DDF model is introduced as Entropy Window two-stage DDF model, which is described as follows.

3.2 Entropy window two-stage DDF model

Suppose there are n DMUs ($j = 1, \dots, n$), which contain t time periods ($t = 1, 2, \dots, T$). In each of these period there are two distinct stages: the agricultural production stage and the hunger eradication and nutritional sustainability stage. We create $T-d+1$ windows to measure the efficiency of each DMU, and each DMU gets d efficiency values in each window. Next, we use the moving average method to obtain the efficiency of DMUs in each period. For DMU _{j} , the d efficiency value is measured in the first window starting from the time period $t = 1$ ($t = 1, 2, \dots, T$). We move to the second time period $t = 2$ and measure the d efficiency value in the second window, and so on, until we move to the $T-d+1$ time period and measure the d efficiency value in the last window. Therefore, for each DMU, the efficiency of total factor production is determined by the t^{th} time period ($t = 1, 2, \dots, d$) in the m^{th} [$m = 1, 2, \dots, (T-d+1)$] window.

In the agricultural production stage there are I inputs x_{ij1}^{tm} ($i = 1, \dots, I$) that produce K good outputs y_{kj1}^{tm} ($k = 1, \dots, K$) and O bad outputs

U_{oj1}^{tm} ($o = 1, \dots, O$), B inputs f_{bj1}^{tm} ($b = 1, \dots, B$) are used to create V good outputs U_{vj1}^{tm} ($v = 1, \dots, V$); and z_{cj1}^{tm} ($c = 1, \dots, C$) is the intermediate output, linking the agricultural production stage (Stage 1) and the

hunger eradication and nutritional sustainability stage (Stage 2). The agricultural production stage (Stage 1) input variables are agricultural employees, land area, and water, while the output variables are good agricultural output (agricultural GDP) and bad agricultural output (wastewater). The hunger eradication and nutrition improvement stage (Stage 2) input variable is government health expenditure, while the output variables are patients with iodine deficiency disorders, patients with foodborne diseases, and improved nutrition. The link between Stage 1 and Stage 2 is the intermediate output of agricultural output.

Under the frontier, the DMU can choose the final output that is most favorable to its maximum value. Thus, the DMU's efficiency under the common boundary can be solved by the following linear programming procedure.

Objective function:

The efficiency of DMUp is calculated by Equation 5 to be:

$$\max \text{GFE} = \theta^{\text{tm}} = w_1^{\text{tm}} \theta_1^{\text{tm}} + w_2^{\text{tm}} \theta_2^{\text{tm}} \quad (5)$$

Subject to:

Agricultural production stage (Stage 1) is represented by Equation 6:

$$\begin{aligned} \sum_j \lambda_j^{\text{tm}} X_{ij1}^{\text{tm}} &\leq X_{ip1}^{\text{tm}} - \theta_1^{\text{tm}} g_{ip1}^{\text{tm}} \quad \forall i, t = 1, 2, \dots, d; m = 1, 2, \dots, (T-d+1) \\ \sum_j \lambda_j^{\text{tm}} y_{kj1}^{\text{tm}} &\geq y_{kp1}^{\text{tm}} - \theta_1^{\text{tm}} g_{kp1}^{\text{tm}} \quad \forall k, t = 1, 2, \dots, d; m = 1, 2, \dots, (T-d+1) \\ \sum_j \lambda_j^{\text{tm}} U_{oj1}^{\text{tm}} &\leq U_{op1}^{\text{tm}} - \theta_1^{\text{tm}} g_{op1}^{\text{tm}} \quad \forall o, t = 1, 2, \dots, d; m = 1, 2, \dots, (T-d+1) \end{aligned} \quad (6)$$

Intermediate output from Stage 1 to Stage 2 is represented by Equation 7:

$$\begin{aligned} \sum_j \lambda_j^{\text{tm}} z_{cj(1,2)}^{\text{tm}} &\geq z_{cp(1,2)}^{\text{tm}} + \theta_1^{\text{tm}} g_{cp(1,2)}^{\text{tm}} \quad \forall c, t = 1, 2, \dots, d; m = 1, 2, \dots, (T-d+1) \\ \sum_j \lambda_j^{\text{tm}} &= 1 \quad \lambda_{j1}^{\text{tm}} \geq 0 \quad \forall j, t = 1, 2, \dots, d; m = 1, 2, \dots, (T-d+1) \end{aligned} \quad (7)$$

Eradicating hunger and improving nutrition sustainable development stage (Stage 2) is represented by Equation 8:

$$\begin{aligned} \sum_j \lambda_j^{\text{tm}} f_{bj2}^{\text{tm}} &\leq f_{bp2}^{\text{tm}} - \theta_2^{\text{tm}} g_{bp2}^{\text{tm}} \quad \forall b, t = 1, 2, \dots, d; m = 1, 2, \dots, (T-d+1) \\ \sum_j \lambda_j^{\text{tm}} U_{vj2}^{\text{tm}} &\leq U_{vp2}^{\text{tm}} - \theta_2^{\text{tm}} g_{vp2}^{\text{tm}} \quad \forall v, t = 1, 2, \dots, d; m = 1, 2, \dots, (T-d+1) \end{aligned}$$

$$\sum_j^n \lambda_{j2}^m = 1 \quad \lambda_{j2}^m \geq 0 \quad \forall j, t = 1, 2, \dots, d; m = 1, 2, \dots, (T - d + 1) \quad (8)$$

Here, w_1^m and w_2^m are stage 1 and stage 2 weights, respectively. From the above results, the overall efficiency, the period efficiency, the division efficiency, and division period efficiency are obtained.

3.3 Input–output indicators and indicator efficiency calculations

The gap between the actual input–output indicators of each DMU and the ideal input–output indicators under the optimal efficiency value represents its room for efficiency improvement from input and output orientation. This study chooses the ratio of the actual input–output value to the calculated optimal input–output value as the efficiency value of the input–output index. The relationship between the optimal value, the actual value, and the efficiency of the indicator is represented by the following Equations 9–11.

$$\text{Efficiency of input indicators} = \frac{\text{Optimal input values}}{\text{Actual input values}} \quad (9)$$

$$\text{Efficiency of output indicators} = \frac{\text{Actual output values}}{\text{Optimal output values}} \quad (10)$$

$$\text{Efficiency of bad output indicators} = \frac{\text{Optimal input values}}{\text{Actual input values}} \quad (11)$$

For inputs and bad outputs, if the actual inputs are greater than the optimal inputs, then the efficiency of the input indicator is less than 1 and is called non-efficient. If the actual inputs are equal to the optimal inputs, then the efficiency of the input and bad output indicators is equal to 1 and is called efficient. If the actual outputs are less than the optimal outputs, then the efficiency of the output indicator is less than 1 and is called non-efficient. If the actual outputs are equal to the optimal outputs, then the efficiency of the output indicator is equal to 1 and is called efficient. The indicator system and the framework diagram of this study are below. The data used in the study were obtained from the China Statistical Yearbook, China Health Statistical Yearbook, and China National Meteorological Science Data Center (Table 2 and Figure 1).

4 Empirical study

4.1 Data description and statistics analysis

This study uses data from a provincial-level sample for 2016–2020. Due to the lack of data for some regions, 29 provinces, municipalities, and autonomous regions are selected for this study (Municipalities and autonomous regions are provincial administrative divisions with the same administrative status as provinces, please note that municipalities such as Beijing are hereafter referred to as provinces).

TABLE 2 Indicator system.

Stage	Variable	Title	Unit
Production stage	Input	Agricultural employees	AE Persons
	Input	Water	water 100 million cubic meters
	Input	Land area	LA 1,000 hectares
	Output	Agricultural gdp	AGDP 100 million RMB
	Output	Agricultural wastewater	AWW 10,000 tons
Recycle stage	Input	Government health expenditures	GHE 100 million RMB
	Output	Patients with iodine deficiency disorders	IDD Persons
	Output	Patients with foodborne diseases	FD Persons
	Output	Improved nutrition	IN
	Carry-over	Agricultural fixed assets	AFA 100 million RMB

The Seventh Five-Year Plan (The starting and ending period of the “Seventh Five-Year Plan” was 1986–1990. The Five-Year Plan, which started in 1953, is a five-year plan for short- and medium-term planning of the country, mainly for major construction projects, distribution of productive forces and important proportionality of the national economy, and setting goals for the development of the national economy), adopted at the Fourth Session of the Sixth National People’s Congress, divided the 30 provinces into east, central, and west regions. The *per capita* GDP of the Inner Mongolia Autonomous Region and the Guangxi Autonomous Region is comparable to that of the 10 western provinces. This means that Guangxi and Inner Mongolia belong to the west region. The regional divisions are shown in the table (Table 3).

This study uses data on 10 input and output indicators from 2016 to 2017 for 29 provinces in China, which are available from the National Bureau of Statistics website and the China Environmental Statistics Yearbook. We calculate the mean, standard deviation, and minimum and maximum values, and the results are kept to two decimal places (Table 4).

4.2 Window data analysis

Referring to Chung et al. (2008), this paper analyzes a series of indicators for each DMU, which include ME, CR, CR_O, and TR. Among them, ME (mean efficiency) reflects the average efficiency of a region over the whole study period, and a higher value indicates higher efficiency. CR (column range) reflects the difference in efficiency of each year between the two windows in which it is located. CR_O (overall column range) is the maximum CR value from 2016 to 2020, which indicates the maximum change in efficiency between windows for different years and reflects the stability of efficiency. TR (total range) refers to the difference between the highest and lowest efficiencies of all windows for the entire study period (Table 5).

Taking Beijing as an example to show the calculation process of each indicator, as shown in the table, each 2 years are divided into a window:

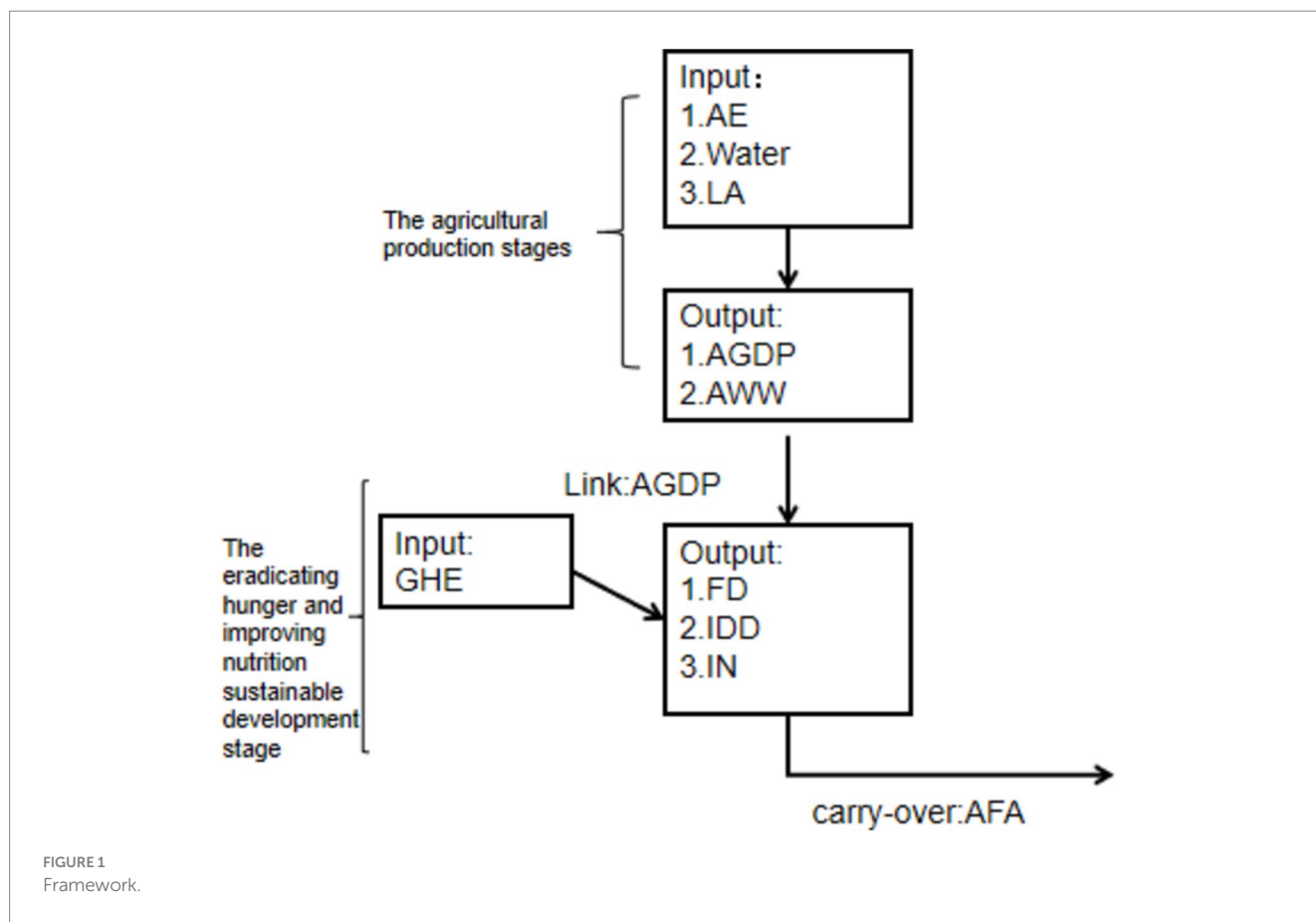


TABLE 3 China's regional divisions.

Region	Provinces, cities, and autonomous regions
East	Beijing, Tianjin, Shanghai, Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan
Central	Henan, Shanxi, Anhui, Hubei, Hunan, Jiangxi, Heilongjiang, Jilin
West	Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Yunnan, Sichuan, Chongqing, Guangxi, Inner Mongolia

2016 to 2017 (W1), 2017 to 2018 (W2), 2018 to 2019 (W3), and 2019 to 2020 (W4). The table reflects the efficiency value corresponding to each year in its window, as well as the ME, CR, CR_O, and TR indicators.

4.2.1 Overall analysis

4.2.1.1 Overall system efficiency analysis

The total efficiency is a comprehensive reflection of the efficiency of the two stages, reflecting the overall efficiency of the entire system from agricultural production inputs to the ultimate goal of eliminating hunger and improving nutrition. It measures whether resources are used effectively throughout the entire chain. In terms of efficiency level, as shown in Table 6, ME in the east region is 0.7347, ME in the central region is 0.5423, and ME in the west region is 0.6842, showing the east region is the best and the central regions is the worst. This may be due to the fact that the eastern region has a developed economy and a high degree of agricultural industrialization. At the same time, the eastern region is close to the consumer market, so there is less waste

of resources from agricultural production to the ultimate goal of achieving food security and nutrition improvement, and the connection and transformation of each link are smoother.

Both CR_O and TR can reflect the stability of efficiency. CR_O in the east region is 0.1065, CR_O in the central region is 0.0586, and CR_O in the west region is 0.1596. The stability of efficiency in the central region is better than that in the east region and better than that in the west region. TR works similarly to CR_O, with smaller TR indicating better stability. However, since CR_O first compares different windows of the same year and then compares different years, the difference is relatively small; TR is used to compare all windows of all years, resulting in larger differences. TR for the east region is 0.1766, TR for the central region is 0.1855, and TR for the west region is 0.2691. Combining years and windows to assess stability, the east region is better than the central region and better than the west region. This means that there are differences and fluctuations in efficiency trends among different regions, and the reasons behind this need to be explored from two aspects: the agricultural production stage and the nutrition improvement stage.

4.2.1.2 Analysis of the agricultural production stages

As shown in Table 7, in the agricultural production stage, ME in the east region is 0.9385, ME in the central region is 0.6015, and ME in the west region is 0.7101, with the east region being higher than the west region, and the central region being the worst. This may be due to the fact that the eastern region itself has a developed economy and has continued to invest in agricultural technology innovation and upgrading during this period, such as further

TABLE 4 Data Description.

Year	Variable	AE	Water	LA	AGDP	AWW	GHE	FD	IDD	IN	AFA
	Unit	Persons	100 million cubic meters	10,000 hectares	100 million RMB	10,000 tons	100 million RMB	Persons	Persons		100 million RMB
2016	Average	7386.21	110.61	2134.73	3556.55	1.8	439.35	1129.1	162560.21	68.96	1670.14
	STD	12520.49	76.6	1652.18	2348.74	1.82	228.76	1126.43	193352.17	2.07	1041.71
	Min	400	6	128.47	300.84	0	82.03	56	0	65.07	55.64
	Max	66,800	313.8	5932.74	9075.6	6.58	1121.83	5,171	793,621	73.18	4958.78
2017	Average	7082.76	111.2	2158.69	3649.21	0.99	482.16	1202.72	157,261	74.31	1944.26
	STD	12604.95	77.53	1670.81	2397.02	1.08	257.74	1096.82	203298.73	2.1	1242.81
	Min	500	5.1	115.48	292.61	0	97.98	48	0	70.17	50.62
	Max	67,700	316.4	6030.97	9140.36	4.63	1307.56	4,717	857,658	78.58	6112.87
2018	Average	6295.6	62.05	1400.89	2052.66	0.63	211.7	936.32	2534.81	1.47	1128.6
	STD	12119.29	76.04	1685.62	2454.69	1.01	278.1	1527.24	5039.22	1.81	1475.39
	Min	400	4.2	109.67	289.58	0	105.55	68	0	63.75	46.07
	Max	65,600	304.8	6119.57	9397.39	5.24	1407.51	7,771	27,423	71.59	7313.95
2019	Average	4510.34	108.4	2187.68	4134.64	0.56	551.45	1332.86	2088.76	69.1	2438.99
	STD	7723.56	75.47	1698.28	2643.48	1.03	306.95	1496.46	5039.22	1.52	1665.86
	Min	300	3.7	109.24	281.7	0.01	106.49	56	0	65.8	42.96
	Max	40,700	303.1	6177.59	9671.67	5.76	1579.6	6,784	27,423	72.83	8140.82
2020	Average	2889.66	106.51	2206.36	4594.24	52.45	629.57	1284.48	1491.62	61.01	2659.17
	STD	3785.91	73.94	1740.37	2981.25	37.76	356.42	1441.63	2340.8	1.23	1890.76
	Min	300	3.2	109.35	263.43	0.82	118.57	49	0	58.47	41.77
	Max	20,100	278.4	6171.61	10190.58	130.2	1772.99	6,621	9,572	63.49	8828.54

TABLE 5 Overall system efficiency in Beijing from 2016 to 2020 and each indicator.

Window	2016	2017	2018	2019	2020	ME	CR_O	TR
W1	0.7397	0.9374				0.9062	0.0910	0.2603
W2		0.8924	1					
W3			1	1				
W4				0.9090	0.7715			
CR	X	0.0450	0	0.0910	X			

improvement in agricultural mechanization and informatization. At the same time, the region has a complete agricultural industrial chain, which can quickly adapt to market changes and obtain higher production benefits. The average efficiency of the agricultural production stage in the western region is between the central and eastern regions, thanks to the support of national policies. Vigorously developing characteristic agriculture has played the comparative advantages of the western region and improved the efficiency of the agricultural production stage in the western region to a certain extent. However, the problems of poor natural environment, fragile ecological environment and relatively weak agricultural infrastructure in the western region have not been completely solved during this period, resulting in limited efficiency improvement. The average efficiency of the agricultural production stage in the central region is relatively low, which shows that the low efficiency of the agricultural

production stage is one of the important reasons for its low overall efficiency. The possible reason is that during the inspection period, the growth of agricultural input in the central region was relatively slow, and some labor force flowed out, resulting in insufficient motivation for agricultural development.

In terms of stability, CR_O of the east region is 0.0717, CR_O of the central region is 0.0605, and CR_O of the west region is 0.1155; the TR value of the eastern region is 0.1327, the TR value of the central region is 0.1427, and the TR value of the western region is 0.1873. In general, the stability of the western region is weaker than that of the eastern and central regions. The reason is that although the eastern region is affected by market changes, it has a solid technical and management foundation and is stable. The agricultural production model in the central region is relatively traditional and mature, so its agricultural production efficiency shows a certain stability.

TABLE 6 Overall system efficiency analysis.

Region	DMU	ME*	Rank	CR_O*	Rank	TR*	Rank
East	Beijing	0.9062	4	0.0910	8	0.2603	28
	Tianjin	0.8789	5	0.0745	12	0.2730	4
	Shanghai	0.9391	2	0.0678	14	0.1257	6
	Liaoning	0.8150	9	0.0570	16	0.2886	13
	Anhui	0.4248	28	0.0166	25	0.0663	21
	Shandong	0.9234	3	0.0037	29	0.2115	9
	Jiangsu	0.6228	16	0.0145	27	0.2233	15
	Zhejiang	0.5014	21	0.0248	24	0.0699	2
	Fujian	0.6871	14	0.6871	1	0.0813	27
	Guangdong	0.4277	27	0.0428	20	0.1183	25
	Hainan	0.9551	1	0.0913	7	0.2242	22
	average	0.7347		0.1065		0.1766	
Central	Heilongjiang	0.7128	12	0.0166	26	0.1575	19
	Jilin	0.5931	18	0.0744	13	0.2598	16
	Henan	0.4867	23	0.1187	6	0.1187	20
	Shanxi	0.4881	22	0.0602	15	0.1282	8
	Anhui	0.4282	26	0.0526	18	0.1088	29
	Hubei	0.5491	20	0.0907	9	0.1659	18
	Hunan	0.6736	15	0.0123	28	0.3054	17
	Jiangxi	0.4064	29	0.0434	19	0.2397	14
	average	0.5423		0.0586		0.1855	
West	Gansu	0.4732	24	0.1533	5	0.2318	26
	Guizhou	0.7418	10	0.0561	17	0.2486	23
	Ningxia	0.8632	6	0.3324	3	0.4140	11
	Qinghai	0.7019	13	0.0837	10	0.2056	10
	Shaanxi	0.7418	11	0.3261	4	0.3671	7
	Yunnan	0.8362	7	0.0409	21	0.0964	3
	Sichuan	0.6094	17	0.0784	11	0.3285	5
	Chongqing	0.8325	8	0.4528	2	0.4528	1
	Guangxi	0.5808	19	0.0343	23	0.1917	24
	Inner Mongolia	0.4614	25	0.0377	22	0.1543	12
	Average	0.6842		0.1596		0.2691	

*Mean efficiency (ME) reflects the average efficiency of a region over the whole study period. Column range (CR) reflects the difference in efficiency of each year between the two windows in which it is located. Overall column range (CR_O) is the maximum CR value from 2016 to 2020. Total range (TR) refers to the difference between the highest and lowest efficiencies of all windows for the entire study period.

Therefore, improving the efficiency of the agricultural production stage is the key. Because high-efficiency agricultural production can increase agricultural product output, ensure supply, resist interference from external factors such as nature and the market, and improve the stability of agricultural production efficiency.

4.2.1.3 Analysis of the eradicating hunger and improving nutrition sustainable development stage

As shown in Table 8, in the eradicating hunger and improving nutrition sustainable development stage, ME in the east region is 0.6772, ME in the central region is 0.6111, and ME in the west region is 0.748. Thus, the west region is better than the east region, which is better than the central region. Obviously, the overall efficiency of the

western region from the agricultural production stage to the sustainable stage of eliminating hunger and improving nutrition is excellent. Therefore, the key to improving the overall efficiency of the western region lies in improving the efficiency of agricultural production in the first stage and its stability. Only a few provinces in the central region have a high level of sustainable efficiency, and most provinces have great room for improvement. The eastern region can focus on how to optimize the efficiency of the stage of eliminating hunger and improving nutrition.

In terms of stability, the CR_O in the eastern region is 0.0603, the CR_O in the central region is 0.0733, and the CR_O in the western region is 0.1928; the TR value in the eastern region is 0.2201, the central region is 0.2939, and the western region is 0.3133. It can

TABLE 7 Efficiency of agricultural production stages.

	DMU	ME*	Rank	CR_O*	Rank	TR*	Rank
East	Beijing	0.9773	8	0.0118	24	0.1819	8
	Tianjin	0.8236	14	0.3272	2	0.5183	2
	Shanghai	0.9983	4	0.0137	23	0.0137	26
	Liaoning	0.8993	12	0.0583	15	0.1868	6
	Anhui	0.6844	19	0.0069	25	0.1879	5
	Shandong	0.9998	3	0.0019	28	0.0019	27
	Jiangsu	1	1	0	29	0	28
	Zhejiang	0.9884	6	0.0840	11	0.0840	22
	Fujian	0.9766	9	0.1307	5	0.1307	15
	Guangdong	0.9760	10	0.1542	4	0.1542	13
	Hainan	1	1	0	29	0	29
	average	0.9385		0.0717		0.1327	
Central	Heilongjiang	0.4662	26	0.0332	18	0.0586	25
	Jilin	0.3976	27	0.0216	21	0.1306	16
	Henan	0.8915	13	0.1591	3	0.1591	11
	Shanxi	0.4711	25	0.0925	9	0.0978	19
	Anhui	0.6033	22	0.0734	12	0.2024	4
	Hubei	0.8160	15	0.0567	17	0.2349	3
	Hunan	0.6702	21	0.0247	19	0.1634	10
	Jiangxi	0.4962	23	0.0231	20	0.0945	21
	average	0.6015		0.0605		0.1427	
West	Gansu	0.3964	28	0.0055	26	0.1576	12
	Guizhou	0.9919	5	0	29	0.0645	24
	Ningxia	0.7424	17	0.6647	1	0.7514	1
	Qinghai	0.4861	24	0.0845	10	0.1383	14
	Shaanxi	0.7916	16	0.1082	7	0.1158	18
	Yunnan	0.6807	20	0.0580	16	0.1282	17
	Sichuan	0.9415	11	0.0159	22	0.1832	7
	Chongqing	0.9813	7	0.0965	8	0.0965	20
	Guangxi	0.7321	18	0.1198	6	0.1653	9
	Inner Mongolia	0.3572	29	0.0024	27	0.0722	23
	Average	0.7101		0.1155		0.1873	

*Mean efficiency (ME) reflects the average efficiency of a region over the whole study period. Column range (CR) reflects the difference in efficiency of each year between the two windows in which it is located. Overall column range (CR_O) is the maximum CR value from 2016 to 2020. Total range (TR) refers to the difference between the highest and lowest efficiencies of all windows for the entire study period.

be seen that the stability of the eastern region is better than that of the central region and better than that of the western region.

4.2.2 Comparison of the efficiency of different windows

4.2.2.1 Overall system efficiency analysis

W1 corresponds to the 2016–2017 window, W2 to the 2017–2018 window, W3 to the 2018–2019 window, and W4 to the 2019–2020 window. As can be seen in Figure 2, in W1–W4 the east region has the highest overall system efficiency, ranging from 0.70 to 0.76, the west region has the second highest, ranging from 0.67 to 0.70, and the central region has the lowest, ranging from 0.51 to 0.59.

This reveals that the central region lags behind the eastern and western regions in all windows. However, both the eastern and central regions show a significant decline in total efficiency in W4 (2019–2020), while the western region stabilizes, so it is necessary to further analyze the impact of the new crown outbreaks of major public health emergencies on total efficiency in 2019–2020 to understand the causes behind.

4.2.2.2 Efficiency analysis of agricultural production stages

As shown in Figure 3, in the agricultural production stage the efficiency values of China’s east, central, and west regions vary greatly during the four windows. The efficiency value of the east region in the

TABLE 8 Analysis of the eradicating hunger and improving nutrition sustainable development stage.

Region	DMU	ME*	Rank	CR_O*	Rank	TR*	Rank
East	Beijing	0.8901	9	0.0601	16	0.3471	8
	Tianjin	0.9531	4	0.1268	6	0.2487	18
	Shanghai	0.9143	7	0.1066	10	0.1796	22
	Liaoning	0.8147	11	0.0985	12	0.3926	5
	Anhui	0.3786	26	0.0265	23	0.1313	23
	Shandong	0.8981	8	0.0061	27	0.2820	15
	Jiangsu	0.4971	22	0.0193	25	0.2977	14
	Zhejiang	0.3403	28	0.0374	21	0.0932	26
	Fujian	0.5953	19	0.0514	18	0.0993	25
	Guangdong	0.2279	29	0.0090	26	0.0511	28
	Hainan	0.9401	5	0.1218	8	0.2990	13
	Average	0.6772		0.0603		0.2201	
Central	Heilongjiang	0.9676	3	0	28	0.2595	17
	Jilin	0.8248	10	0.1408	5	0.4151	4
	Henan	0.3645	27	0.0909	13	0.0909	27
	Shanxi	0.6000	18	0.1111	9	0.2319	19
	Anhui	0.4277	25	0.0402	20	0.2250	21
	Hubei	0.4915	23	0.1233	7	0.3199	11
	Hunan	0.7598	14	0.0256	24	0.4317	3
	Jiangxi	0.4532	24	0.0544	17	0.3772	6
	Average	0.6111		0.0733		0.2939	
West	Gansu	0.6240	17	0.2598	3	0.3031	12
	Guizhou	0.6606	15	0.0749	14	0.3352	9
	Ningxia	0.9861	2	0.0000	28	0.1114	24
	Qinghai	0.9343	6	0.1978	4	0.3274	10
	Shaanxi	0.7807	13	0.5393	2	0.5393	2
	Yunnan	0.9937	1	0.0499	19	0.0499	29
	Sichuan	0.5060	21	0.1045	11	0.3555	7
	Chongqing	0.7847	12	0.6037	1	0.6037	1
	Guangxi	0.5785	20	0.0343	22	0.2289	20
	Inner Mongolia	0.6314	16	0.0635	15	0.2784	16
	average	0.748		0.1928		0.3133	

*Mean efficiency (ME) reflects the average efficiency of a region over the whole study period. Column range (CR) reflects the difference in efficiency of each year between the two windows in which it is located. Overall column range (CR_O) is the maximum CR value from 2016 to 2020. Total range (TR) refers to the difference between the highest and lowest efficiencies of all windows for the entire study period.

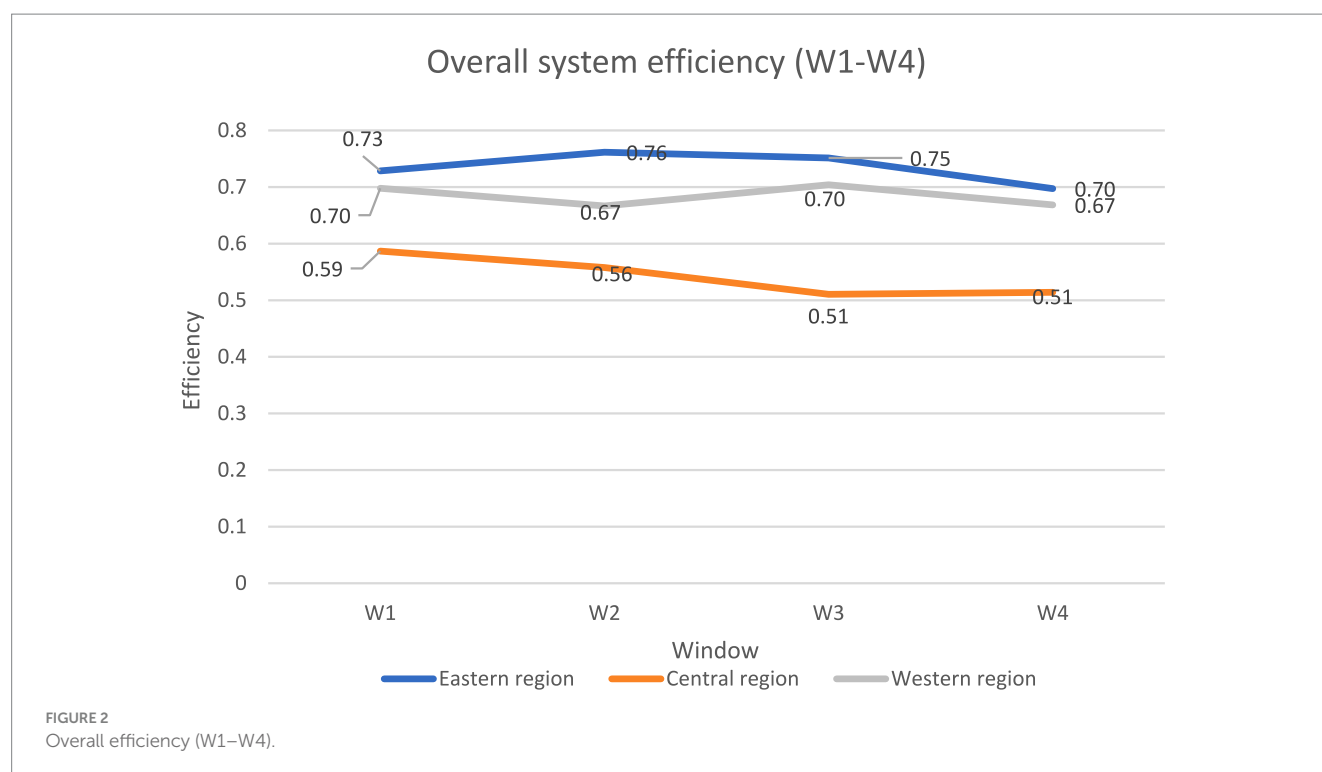
agricultural production stage is much higher than that of the central region and the west region, maintaining the same trend as total efficiency. The east region has better economic conditions and therefore pays more attention to the introduction of advanced agricultural production technology. During the period W1–W4, efficiency values at the stage of agricultural production fluctuated in the range of 0.92–0.95 in the eastern region, 0.69–0.76 in the western region, and 0.58–0.64 in the central region.

Further observation reveals that the Central Region shows a significant increase from window W3 to W4 compared to the Eastern and Western Regions. Especially in the case of an epidemic, the agricultural productivity of the Central region is still able to

maintain its growth. It can be seen that the experiences and practices of the central region with regard to the stage of agricultural production have important lessons for responding to the issue of food security in the context of the impact of major public health emergencies.

4.2.2.3 Efficiency analysis of the eradicating hunger and improving nutrition sustainable development stage

As shown in Figure 4, in the stage of the eradicating hunger and improving nutrition sustainable development from W1 to W4, the efficiency values of China’s east, central, and west regions in this stage are relatively close to each other. All fluctuate within



the interval of 0.64–0.75, with the central and west regions showing a trend of decreasing, then increasing, and decreasing again, and the east region showing a trend of increasing and then decreasing. The west region, except for its efficiency value of W2 that drops steeply to the lowest value of 0.67, has efficiency values in W1, W3, and W4 that are significantly higher than those in the east and central regions. In addition, during the period from W3 to W4, which was during the COVID-19, the efficiency values of both the eastern and central regions showed a decreasing trend, while the efficiency of the western region remained unchanged. The possible reasons for this are that the population density in the west is relatively low, and the impact on the food supply system caused by the stoppage of work and production as a result of the epidemic prevention and control measures is relatively small, and on the other hand, the western region is more self-sufficient, with a relatively independent production and consumption system. In contrast, the eastern and central regions are characterized by high population mobility, and the supply chain is blocked under the epidemic, resulting in lower efficiency in the sustainable phase of hunger eradication and nutrition improvement. It can be seen that during the period from W3 to W4, the efficiency of the eradicating hunger and improving nutrition sustainable development stage in each region was affected by the impact of the new crown epidemic to different degrees.

4.3 Efficiency analysis for the COVID-19 period

In order to study the impact of COVID-19 on eradicating hunger, reaching food security, and improving nutrition, this section focuses

on the efficiency of window W4 (2019 to 2020), the period of the epidemic. It uses indicator WE to measure the efficiency of the window for W4 and indicator EV to measure the growth rate of efficiency during the window.

4.3.1 Overall system efficiency analysis for the period COVID-19

As shown in Table 9, during the period of COVID-19, in terms of overall system efficiency WE, the east region (0.6972) is better than the west region (0.6685), which is better than the central (0.5139). Among the 29 provinces, six provinces have total efficiency values >0.8, of which 4 are located in the east region, and 2 are located in the west region. Shanghai (0.9549), Shandong (0.8942), and Hainan (0.8879) are the three provinces with the highest efficiency value, all of which are in the east region. The three provinces with the lowest efficiency values are Guangdong (0.4230), Shanxi (0.4242), and Hebei (0.4363). Guangdong and Hebei are located in the east region, and Shanxi is located in the central region. Thus, it can be seen that the overall system efficiency in east China varies considerably across provinces.

During the period of COVID-19, EV in the east region is −8.94%, EV in the central region is −5.09%, and EV in the west region is −14.78%. During the 2 years of COVID-19, the overall system efficiency values of the east, central, and west regions show a decreasing trend, in which the west region has the largest decreasing trend, followed by the east region, and then the central region. Only 8 provinces present an increase in overall efficiency, of which 2 provinces are in the east region, 3 in the central region, and 3 in the west region. The three provinces with the largest increases are Jiangxi (68.55%), Guizhou (30.99%), and Hunan (10.87%), and the three provinces with the largest decreases are Heilongjiang (−40.36%), Chongqing (−37.39%) and Shaanxi (−32.61%).

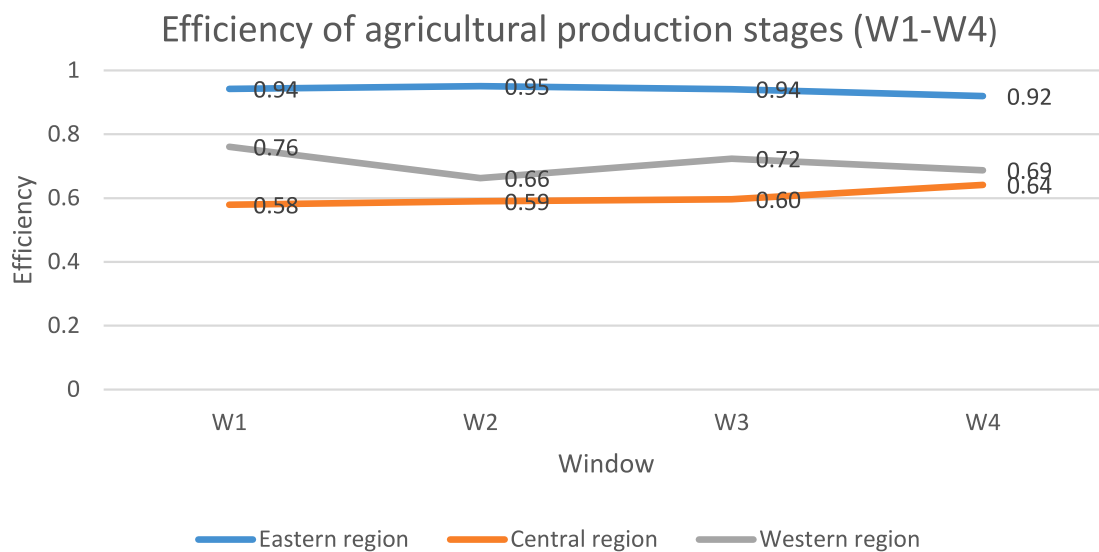


FIGURE 3
Efficiency of agricultural production stages (W1–W4).

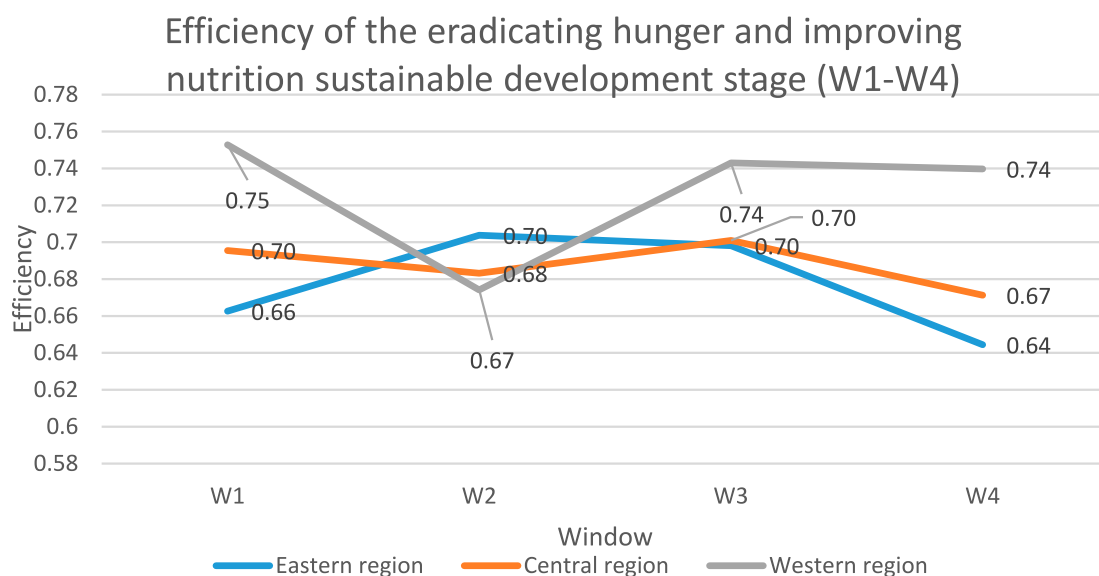


FIGURE 4
Efficiency of the eradicating hunger and improving nutrition sustainable development stage (W1–W4).

4.3.2 Analysis of the efficiency of agricultural production stages during COVID-19

As can be seen from Table 10, in terms of the efficiency value WE in the agricultural production stage during the COVID-19 period, the east region (0.9197) is higher than the west region (0.6874), which is slightly higher than the central region (0.6413). Among the 29 provinces, 14 provinces' WE is higher than 0.8, and only 1 province (Ningxia) has it lower than 0.3. Eight provinces have WE equal to 1, of which 7 provinces are in the east region and 1 province in the west region. During the COVID-19 period, the east region still maintains a high level of efficiency of agricultural production stages and is much better than the central and west regions.

In terms of EV during the COVID-19 period in the agricultural production stage, it is 3.68% in the east region, 11.17% in the central

region, and 2.60% in the west region. The largest increase in the value of efficiency is in the central region, the second largest in the east region, and the smallest in the west region. As a result, the central region is an important food production base in China, and the increase in its agricultural productivity remained outstanding during the Xinguan epidemic, playing a crucial role in guaranteeing China's food security.

4.3.3 Analysis of the efficiency of the hunger eradication and nutritional sustainability phase during COVID-19

As can be seen from Table 11, in the stage of eradicating hunger and improving nutrition sustainable development during COVID-19, WE is higher in the west region (0.7397) than in the east region

TABLE 9 Overall system efficiency during COVID-19.

Region	DMU	2019	2020	we	Rank	EV	Rank
East	Beijing	0.9090	0.7715	0.8403	5	−15.13%	17
	Tianjin	0.7409	0.7478	0.7444	9	0.94%	6
	Shanghai	1.0000	0.9098	0.9549	1	−9.02%	13
	Liaoning	0.7667	0.6890	0.7279	10	−10.13%	14
	Anhui	0.4348	0.4378	0.4363	27	0.70%	7
	Shandong	1.0000	0.7885	0.8942	2	−21.15%	18
	Jiangsu	0.5682	0.5650	0.5666	19	−0.58%	9
	Zhejiang	0.5324	0.4774	0.5049	22	−10.32%	15
	Fujian	0.7109	0.6673	0.6891	11	−6.13%	12
	Guangdong	0.4339	0.4121	0.4230	29	−5.04%	10
	Hainan	1.0000	0.7758	0.8879	3	−22.42%	20
	Average			0.6972		−8.94%	
Central	Heilongjiang	0.7228	0.4310	0.5769	17	−40.36%	29
	Jilin	0.6340	0.4966	0.5653	20	−21.67%	19
	Henan	0.4610	0.4126	0.4368	26	−10.51%	16
	Shanxi	0.5046	0.3437	0.4242	28	−31.88%	25
	Anhui	0.4249	0.4605	0.4427	25	8.38%	4
	Hubei	0.6523	0.4949	0.5736	18	−24.12%	22
	Hunan	0.5925	0.6568	0.6247	14	10.87%	3
	Jiangxi	0.3476	0.5859	0.4668	24	68.55%	1
	Average			0.5139		−5.09%	
West	Gansu	0.5858	0.4523	0.5191	21	−22.78%	21
	Guizhou	0.6456	0.8457	0.7457	8	30.99%	2
	Ningxia	0.6243	0.5860	0.6052	15	−6.13%	11
	Qinghai	0.7642	0.5586	0.6614	12	−26.90%	23
	Shaanxi	0.8967	0.6043	0.7505	7	−32.61%	27
	Yunnan	0.8699	0.8749	0.8724	4	0.58%	8
	Sichuan	0.7794	0.5301	0.6547	13	−31.99%	26
	Chongqing	1.0000	0.6261	0.8131	6	−37.39%	28
	Guangxi	0.5671	0.6027	0.5849	16	6.27%	5
	Inner Mongolia	0.5549	0.4006	0.4777	23	−27.81%	24
	Average			0.6685		−14.78%	

(0.6444), which is higher than the central region (0.5432). Among the 29 provinces, nine have an efficiency value higher than 0.8, and only one (Guangdong) has an efficiency value lower than 0.3. The 3 provinces with the highest WE are Tianjin (1.0000), Yunnan (0.9997), and Ningxia (0.9443), and the 3 provinces with the lowest WE are Guangdong (0.2306), Jiangxi (0.3323), and Zhejiang (0.3399).

In the stage of eradicating hunger and improving nutrition sustainable development during COVID-19, the EV value of the east region is −15.53%, the EV value of the central region is −16.76%, and the EV value of the west region is −18.94%. The efficiency values of the east, central, and west regions of China show a downward trend, with the west region showing the greatest decline, the central region in second, and then the east region. It can be seen that in the stage of

eradicating hunger and improving nutrition sustainable development, the eastern, central and western parts of the country were strongly affected by the epidemic. During this phase, all three regions experienced a considerable drop in efficiency, with the central and western regions being particularly affected.

From the previous section, it can be seen that the eastern region is in the leading position in terms of efficiency in the agricultural production stage, but its efficiency performance in the eradicating hunger and improving nutrition sustainable development stage during the COVID-19 period is poor, which indicates that the eastern region has not been able to successfully transform the efficiency advantage in the agricultural production stage into the actual effectiveness in the eradicating hunger and improving nutrition sustainable development stage. This shows that the major public health emergency of

TABLE 10 Efficiency of agricultural production stages during COVID-19.

Region	DMU	2019	2020	WE	Rank	EV	Rank
East	Beijing	0.8181	1.0000	0.9090	12	22.24%	3
	Tianjin	0.4817	0.4957	0.4887	23	2.89%	12
	Shanghai	1.0000	1.0000	1.0000	1	0.00%	18
	Liaoning	0.9503	0.9588	0.9546	10	0.90%	16
	Anhui	0.7124	0.8153	0.7639	16	14.45%	6
	Shandong	1.0000	1.0000	1.0000	1	0.00%	18
	Jiangsu	1.0000	1.0000	1.0000	1	0.00%	18
	Zhejiang	1.0000	1.0000	1.0000	1	0.00%	18
	Fujian	1.0000	1.0000	1.0000	1	0.00%	18
	Guangdong	1.0000	1.0000	1.0000	1	0.00%	18
	Hainan	1.0000	1.0000	1.0000	1	0.00%	18
	Average			0.9197		3.68%	
Central	Heilongjiang	0.4455	0.4957	0.4706	26	11.26%	8
	Jilin	0.4104	0.4873	0.4488	27	18.74%	5
	Henan	0.8728	0.8557	0.8643	14	−1.96%	27
	Shanxi	0.4229	0.5207	0.4718	25	23.13%	2
	Anhui	0.6680	0.7083	0.6881	20	6.02%	10
	Hubei	0.7993	1.0000	0.8996	13	25.11%	1
	Hunan	0.7415	0.7544	0.7480	18	1.75%	13
	Jiangxi	0.5250	0.5530	0.5390	21	5.33%	11
	Average			0.6413		11.17%	
West	Gansu	0.4780	0.4846	0.4813	24	1.38%	15
	Guizhou	1.0000	0.9355	0.9677	9	−6.45%	28
	Ningxia	0.2486	0.3002	0.2744	29	20.76%	4
	Qinghai	0.5283	0.5317	0.5300	22	0.63%	17
	Shaanxi	0.7934	0.7916	0.7925	15	−0.23%	26
	Yunnan	0.7398	0.7507	0.7452	19	1.48%	14
	Sichuan	1.0000	0.8826	0.9413	11	−11.74%	29
	Chongqing	1.0000	1.0000	1.0000	1	0.00%	18
	Guangxi	0.7073	0.7947	0.7510	17	12.36%	7
	Inner Mongolia	0.3756	0.4049	0.3902	28	7.82%	9
	average value			0.6874		2.60%	

COVID-19 had a huge impact in the eradicating hunger and improving nutrition sustainable development stage.

Having explored the impact of the new crown epidemic on the efficiency of the stage of eradicating hunger and improving nutrition sustainable development in various regions, we have further reflected on the key factors that will guarantee the realization of this goal in the context of the epidemic. Indeed, agriculture in China is characterized to some extent by an energy-intensive industry, which has a crucial impact on hunger eradication and nutrition in the current context. As we know, agricultural machinery requires energy to run, and fertilizer and pesticide production and transportation also consume large amounts of energy. In the context of the epidemic, energy management has become a key element in influencing the food supply and the eradicating hunger and improving nutrition sustainable development stage.

On the one hand, effective energy management ensures the stable operation of agricultural production, which in turn guarantees the stability of the food supply and provides the material basis for the phase of improving nutrition in the fight against hunger. On the other hand, effective energy management also affects the sustainability of hunger eradication and improved nutrition. The rational use of energy in food processing, storage and transportation can reduce costs and increase efficiency, so that nutritious food can be more widely distributed to areas and populations in need, thus contributing to distribution and sustainable development, which is of great significance for regions that are striving to maintain the efficiency of the sustainable phase of hunger eradication and improved nutrition in the face of the impact of epidemics.

TABLE 11 Efficiency of the eradicating hunger and improving nutrition sustainable development stage during COVID-19.

Region	DMU	2019	2020	WE	Rank	EV	Rank
East	Beijing	1.0000	0.6953	0.8477	8	−30.47%	22
	Tianjin	1.0000	1.0000	1.0000	1	0.00%	4
	Shanghai	1.0000	0.8712	0.9356	4	−12.88%	14
	Liaoning	0.7174	0.6074	0.6624	14	−15.33%	15
	Anhui	0.3785	0.3324	0.3555	25	−12.18%	13
	Shandong	1.0000	0.7180	0.8590	6	−28.20%	19
	Jiangsu	0.4243	0.4199	0.4221	23	−1.03%	6
	Zhejiang	0.3765	0.3032	0.3399	27	−19.45%	16
	Fujian	0.6146	0.5565	0.5855	18	−9.46%	9
	Guangdong	0.2452	0.2161	0.2306	29	−11.89%	12
	Hainan	1.0000	0.7010	0.8505	7	−29.90%	21
	Average			0.6444		−15.53%	
Central	Heilongjiang	1.0000	0.7405	0.8702	5	−25.95%	17
	Jilin	0.8819	0.6027	0.7423	11	−31.66%	23
	Henan	0.3381	0.3454	0.3418	26	2.15%	3
	Shanxi	0.6585	0.4774	0.5680	19	−27.51%	18
	Anhui	0.3867	0.3478	0.3673	24	−10.04%	10
	Hubei	0.6465	0.3265	0.4865	22	−49.49%	28
	Hunan	0.5940	0.6800	0.6370	17	14.48%	2
	Jiangxi	0.3427	0.3220	0.3323	28	−6.07%	8
	Average			0.5432		−16.76%	
West	Gansu	0.7527	0.5332	0.6429	15	−29.16%	20
	Guizhou	0.5275	0.8337	0.6806	13	58.05%	1
	Ningxia	1.0000	0.8886	0.9443	3	−11.14%	11
	Qinghai	1.0000	0.6726	0.8363	9	−32.74%	24
	Shaanxi	1.0000	0.5823	0.7912	10	−41.77%	27
	Yunnan	1.0000	0.9993	0.9997	2	−0.07%	5
	Sichuan	0.7058	0.4294	0.5676	20	−39.17%	26
	Chongqing	1.0000	0.4659	0.7329	12	−53.41%	29
	Guangxi	0.5767	0.5528	0.5647	21	−4.14%	7
	Inner Mongolia	0.7762	0.4979	0.6371	16	−35.86%	25
	Average			0.7397		−18.94%	

5 Conclusions and policy implications

5.1 Conclusion

First of all, the total efficiency measured in this paper fully demonstrates the comprehensive results of the whole system from the initial inputs of agricultural production to the final realization of the goal of hunger eradication and nutrition improvement, which measures the effective utilization of resources in the whole chain process. From 2016 to 2020, in terms of the total efficiency level, the average efficiency value is the highest in the eastern region, the second in the western region, and the lowest in the central region; the stage of agricultural production also shows the highest average efficiency value in the east, the second highest in the west, and the lowest in the

center; in the stage of eradicating hunger and improving nutritional sustainability, the western region has the highest average efficiency value, the second highest in the east, and the lowest in the center. The higher total efficiency in the eastern region is attributed to the combination of its developed economy, high degree of industrialization of agriculture, and proximity to the consumer market; however, the central region, as a concentration of China's large agricultural provinces, has a low total efficiency. In view of this, it is necessary to focus on the problems in the central region.

Second, using the window analysis, combining the agricultural production stage, the eradicating hunger and improving nutritional sustainability stage, and the system as a whole, the total efficiency values of the eastern and western regions, the efficiency values of the eastern and western regions in the agricultural production stage, and

the efficiency values of the three regions in the eradicating hunger and improving nutritional sustainability stage showed a significant decrease in the W3 - W4 period. However, the Central Region shows a certain increase in the W3 - W4 period. Although the central region is still in a state of low efficiency, this increase in the face of shocks during the epidemic implies that the central region has some resilience or adaptive mechanisms under certain conditions.

Finally, to further explore the impact of major emergencies on eradicating hunger, achieving food security and improving nutrition, specific analyses were conducted for the COVID-19 period. During the COVID-19 period, in terms of the overall efficiency level, the Eastern region had the highest average efficiency value, followed by the Western region, and the Central region had the lowest. At the same time, the overall efficiency values of all three regions showed a decreasing trend, with the lowest decrease in the central region, which indicates that the central region was the least affected by the epidemic, and this is mainly due to the fact that the central region still maintained the highest increase in the agricultural production stage during the COVID-19 period. However, in the eradicating hunger and improving nutritional sustainability stage, the efficiency values of all regions show a decreasing trend, and the efficiency value of the central region is the lowest, which shows that the central region has the problems of insufficient capacity to deal with public health emergencies, poor connection between agricultural production and nutrition improvement, and insufficient rationalization of resource allocation and utilization in this stage, and also reflects that the central region still has a problem of enhancing the efficiency of the eradicating hunger and improving nutritional sustainability stage, which indicates that the central region is still the least affected by the epidemic. At the same time, it also reflects that the central region still has a great deal of room for improvement in enhancing the efficiency of the permanent phase of hunger eradication and nutritional improvement, and that efforts in the areas of policy support, technological innovation, and industrial synergy need to be further strengthened in order to enhance the central region's ability to achieve the goals of hunger eradication and nutritional improvement in the face of major emergencies.

5.2 Implications for theory and practice

5.2.1 Establishing a sound natural disaster prevention and control mechanism to effectively respond to natural disasters in agriculture

In order to prevent natural disasters as best as possible and reduce the negative impact of natural disasters on agricultural production, the relevant government departments should establish a sound natural disaster prevention and control mechanism. First, investments in the configuration of facilities to cope with natural disasters in agriculture should be increased, and routine maintenance should be carried out on a daily basis to ensure that they function properly in the event of a natural disaster. Second, it is necessary to strengthen the reserves of natural disaster emergency supplies and improve the natural disaster risk management mechanism. Finally, disaster prevention awareness and capacity of agricultural operators need to be enhanced.

5.2.2 Accelerating agricultural technological innovation and modernizing agricultural production

In order to improve the level of agricultural production, it is necessary to continuously accelerate agricultural technological innovation and strengthen the construction of modernized agricultural production. Research institutes, colleges and universities, and new business entities should actively engage in agricultural science and technology research. At the same time, the sharing of agricultural scientific and technological resources among regions should be promoted in order to facilitate agricultural technological innovation to better support the development of agricultural production. In addition, the strength and intensity of support for the cultivation of the agricultural technology industry should be increased, and the latest scientific research results and invention patents should be invested in actual agricultural production, so as to realize the transformation and application of agricultural technology more quickly. Attention should be paid to the development of smart agriculture by combining modern science and technology with agricultural cultivation in order to achieve unmanned, automated, and intelligent management.

5.2.3 Establishment of special support funds to promote the resumption of work and production, and enhancement of the effectiveness of emergency prevention and control strategies to increase production efficiency

Wuhan City introduced the new agricultural business entities "relief eleven," for example, in the financial, fiscal and tax, insurance, land, project construction and other eleven levels, the implementation of a series of specific and quantifiable initiatives, aimed at new agricultural business entities to support, to help reduce the negative impact of the epidemic, to accelerate the resumption of work of the agricultural enterprise. The aim is to support new agricultural enterprises, help them reduce the negative impact of the epidemic and speed up the pace of agricultural enterprises resuming work and production. The main support targets cover four types of subjects: family farms, farmers' cooperatives, leading agricultural enterprises and large farming households, and the core support dimensions include financial support, fiscal support, factor support and service guarantee, etc., so as to effectively solve the difficulties faced by new agricultural management subjects. For developing countries, they can learn from this practice and clarify the precise allocation criteria and scientific use process of the special support funds to ensure that the funds flow accurately and precisely to the most urgently needed business entities and key projects. At the same time, an effective supervision and scientific evaluation mechanism for the use of funds should be established to ensure the transparency and effectiveness of the use of funds, so that each fund can maximize its effectiveness, promote the successful resumption of work and production by agricultural business entities, and promote the sound development of the agricultural industry, thus providing strong support for the recovery and sustainable development of the agricultural economy of developing countries in the face of major emergencies.

5.2.4 Building green food policy frameworks for sustainable development trends

Emerging trends toward decarbonization, circularity and sustainability had a positive impact on food supply by promoting environmentally friendly agricultural practices, efficient resource use and long-term ecological balance. These trends help to ensure food security while protecting and improving agro-ecosystems and supporting the achievement of the United Nations sustainable development goals. A green food policy framework should be developed in response to the impact of emerging decarbonization, circularity and sustainability trends on food supply. In response to the decarbonization trend, subsidy incentives should be established, such as subsidies for farmers using decarbonized fertilizers and pesticides, tax incentives for relevant enterprises, and the development and regulation of production standards; in response to the recycling trend, infrastructure investment should be increased, such as the construction of facilities for the treatment of agricultural wastes and systems for recycling water resources; and in response to the sustainability trend, policies on the management of land and water resources should be formulated, and agroecological compensation mechanisms should be established to protect ecosystems and enhance agro-genetic diversity. In response to sustainability trends, land and water management policies need to be developed, agro-ecological compensation mechanisms need to be established to protect ecosystems, and agro-genetic diversity conservation needs to be strengthened in order to ensure that the food supply develops on an environmentally friendly, resource-efficient and long-term sustainable track.

5.2.5 Improve the supply chain system of agricultural products to ensure the effective connection between agriculture and nutrition

Strengthening supply chain infrastructure. Invest in the construction of modernized storage facilities for agricultural products, equipped with advanced cold storage, freshness preservation, ventilation and other equipment, to ensure the quality and nutritional stability of agricultural products in the storage process. For example, building large-scale intelligent grain warehouses in major grain-producing areas, applying automatic temperature and humidity regulation, pest monitoring and other technologies to ensure grain storage safety; establishing an emergency supply chain management mechanism, formulating an emergency response plan for the supply chain of agricultural products in the event of major emergencies, and clarifying the responsibilities and tasks of various departments and links. This includes how to safeguard the production, acquisition,

transportation and distribution of agricultural products in an orderly manner during emergencies such as epidemics and natural disasters. For example, it provides for the opening of “green channels” for the transportation of agricultural products during the sealing and control of epidemics, so as to ensure the smooth flow of agricultural materials and agricultural products.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZF: Writing – review & editing, Writing – original draft, Conceptualization. QX: Writing – review & editing, Writing – original draft, Methodology. YG: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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